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VOYO

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A
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I
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HERMOSILLO
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C. DEL BALAURTE
C. LA CALA
C. GOYENA
C. DE TRINCHERAS
C. CARRIZALA
C. DEL CARRIZAL
C. DE CHUPADEROS
C. DE MORADILLAS
C. PRIETO
CERRO PINTO
CERRO CAPOMAS
CERRO LAS JALOSTOTAS
CERRO SAN PEDRO
CERRO TORDILLO
CERRO LISTA BLANCA (approx.)
SIERRA DEL ALAMILLO
SIERRA DEL CHIVATO
SIERRA CAJON DE UNALAMA
SIERRA DE BACATETE
SIERRA DE LOS TANQUES
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SIERRA DE LOS CHUPADEROS
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SIERRA DE LOS CAPOMAS
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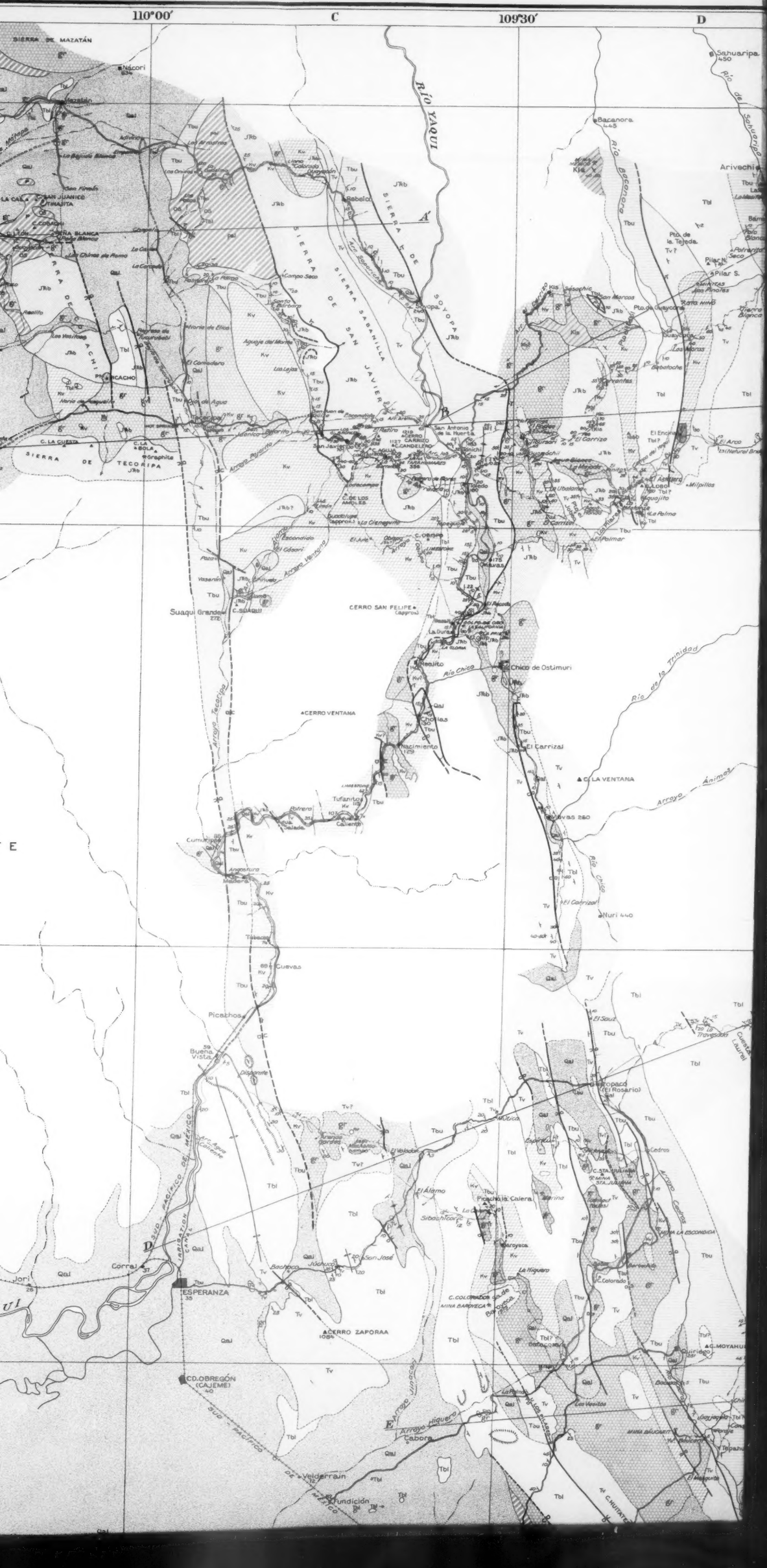
SIERRA DE LOS PINT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D
SIERRA DE MAZATÁN
Nácori
Mazatán
RÍO YAQUI
Sahuaripa
Río de Sahuaripa
Bacanora
Río Bacanora
Arivechi
SIERRA DE SOYOPA
SIERRA SABANILLA
SIERRA DE SAN JAVIER
SIERRA DE TECORIPA
Rebeico
Soyopa
Pto. de la Tejeda
Pilar S.
Pilar Nvo.
Sasochic
San Marcos
Pto. de Guayacora
Las Manas
Babotoche
El Carrizo
El Arco
El Lobo
Aguajito
La Palma
Milpillas
Suaqui Grande
CERRO SAN FELIPE
Chico de Ostimuri
Río Chico
Río de la Trinidad
CERRO VENTANA
El Carrizal
C. LA VENTANA
Arroyo Ánimas
Nuri
Cumuripa
Cuevas
Picachos
Buena Vista
Tabasco
Angostura
Tufanitos
Caliente
Nacimiento
Real Viejo
Real Nuevo
Arroyo Tecoripa
Arroyo Palomito
Arroyo Verdugo
Arroyo Blanco
Arroyo Escondido
Arroyo Cabora
Arroyo Higuera
Arroyo Junacal
Arroyo Cuesta Laurel
Arroyo Cuesta Cajones
Arroyo Cuesta Caballos
Arroyo Cuesta Cedros
Arroyo Cuesta Bermejo
Arroyo Cuesta Bonanza
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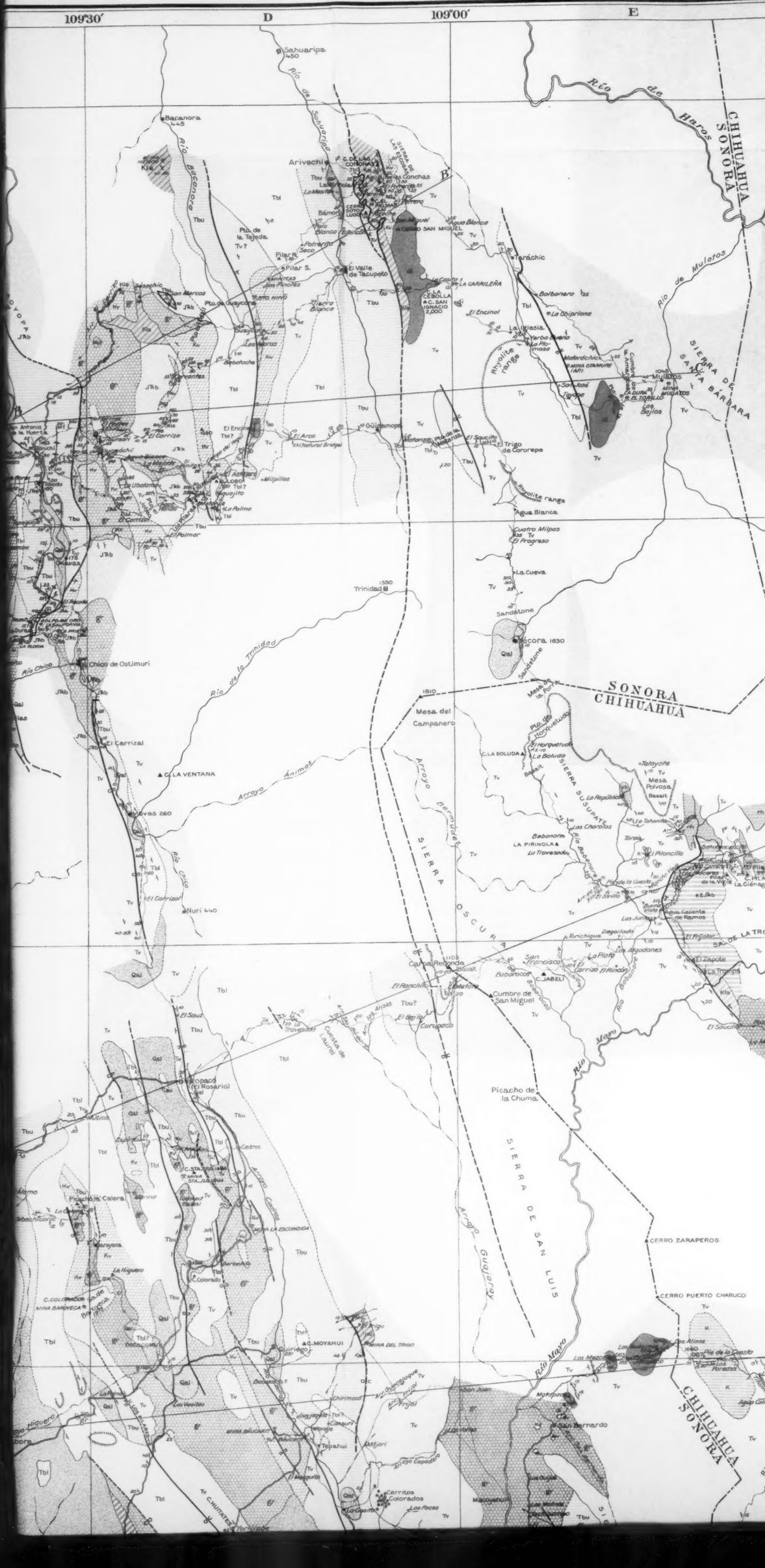
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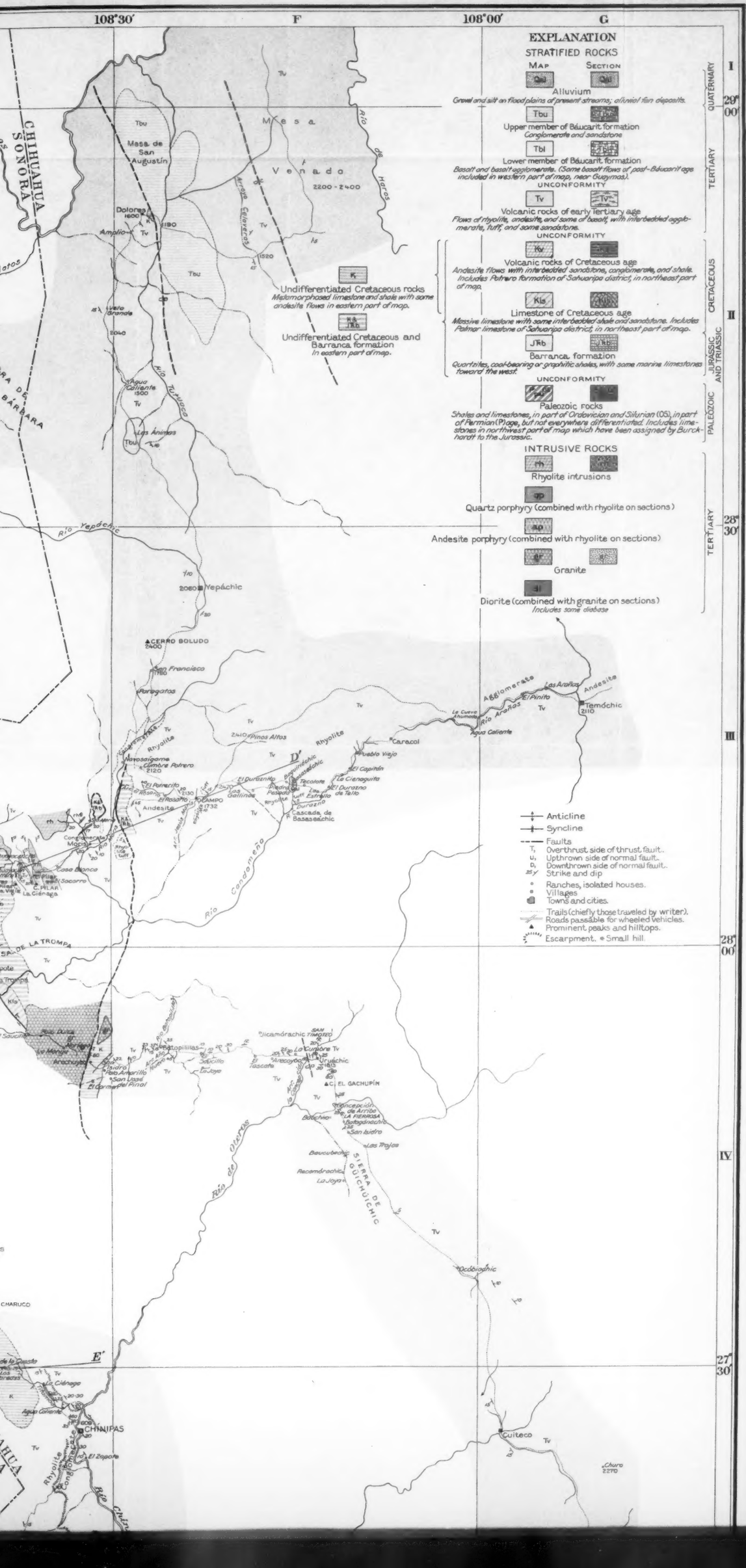
Sahuaripa 450
Río de Sahuaripa
Río de Haros
CHIHUAHUA
SONORA
Bacanora 445
Río Bacanora
Arivechi
Pto. de la Tejeda
Pilar N.
Pilar S.
El Valle de Tacupeto
Pto. de Guaycora
Río de Mulatos
Toráchic
Balbonaro
La Chipriona
El Encinal
La Iglesia
Yerba Buena
La Plomosa
Mulatos
SIERRA DE SANTA BÁRBARA
Rhyolite range
Güiguimopa
El Arco (Natural Bridge)
El Trigo de Cororepa
Agua Blanca
Cuatro Milpas
El Progreso
La Cueva
Trinidad 1350
Sandstone
Escora 1630
Río de la Trinidad
Chico de Ostimuri
Río Chico
El Carrizal
C. LA VENTANA
Arroyo Ánimas
Nuri 440
SONORA
CHIHUAHUA
Mesa del Campanero 1810
Pto. de Norquehuca
El Norquehuca
La Boluda
C. LA BOLUDA
SIERRA SUSUPARE
Mesa Polvosa
Las Charolas
Babonora
LA PIRINOLA
La Travesada
Río Babonora
El Piloncillo
Arroyo Bermudez
SIERRA OSCURA
Agua Caliente de Ramos
Las Juntas
Torichique
Piedra la Cuesta
El Pitaloro
El Zapote
La Trompa
Campo Redondo 1109
San Francisco
El Carrizo
El Rincón
Los Algodones
La Piloa
C. JABELI
El Ranchito
Cumbre de San Miguel
El Bajío
Curugoco
Río Mayo
Picacho de la Chuma
Chinopaco (El Rosario)
SIERRA DE SAN LUIS
CERRO ZARAPEROS
CERRO PUERTO CHARUCO
Los Alisos
Pta. de la Cuesta
Los Paredes
Arroyo Cuchujaqui
Picacho la Calera
C. COLORADO
MINA BARQUEZA
C. MOYAHUI
MINA DEL TRIGO
Quirieco
Los Mezcales
Matapisca
San Bernardo
Chinimoca
Tepahui
Majari
Cerritos Colorados
Los Foces
Macoyahui
Los Bujas
Los Monos
CHIHUAHUA
SONORA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F
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G
EXPLANATION
STRATIFIED ROCKS
MAP
SECTION
Alluvium
Gravel and silt on flood plains of present streams; alluvial fan deposits.
Tbu
Upper member of Báucarit formation
Conglomerate and sandstone
Tbl
Lower member of Báucarit formation
Basalt and basalt agglomerate. (Some basalt flows of post-Báucarit age included in western part of map, near Guaymas).
UNCONFORMITY
Tv
Volcanic rocks of early Tertiary age
Flows of rhyolite, andesite, and some of basalt, with interbedded agglomerate, tuff, and some sandstone.
UNCONFORMITY
Kv
Volcanic rocks of Cretaceous age
Andesite flows with interbedded sandstone, conglomerate, and shale. Includes Potrero formation of Sahuaripa district, in northeast part of map.
Kls
Limestone of Cretaceous age
Massive limestone with some interbedded shale and sandstone. Includes Palmar limestone of Sahuaripa district, in northeast part of map.
JTrb
Barranca formation
Quartzites, coal-bearing or graphitic shales, with some marine limestones toward the west.
UNCONFORMITY
Paleozoic rocks
Shales and limestones, in part of Ordovician and Silurian (OS), in part of Permian (P) age, but not everywhere differentiated. Includes limestones in northwest part of map which have been assigned by Burckhardt to the Jurassic.
INTRUSIVE ROCKS
rh
Rhyolite intrusions
qp
Quartz porphyry (combined with rhyolite on sections)
ap
Andesite porphyry (combined with rhyolite on sections)
Granite
di
Diorite (combined with granite on sections)
Includes some diabase
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC AND TRIASSIC
PALEOZOIC
TERTIARY
Undifferentiated Cretaceous rocks
Metamorphosed limestone and shale with some andesite flows in eastern part of map.
Undifferentiated Cretaceous and Barranca formation
In eastern part of map.
Anticline
Syncline
Faults
Overthrust side of thrust fault.
Upthrown side of normal fault.
Downthrown side of normal fault.
Strike and dip
Ranches, isolated houses.
Villages
Towns and cities.
Trails (chiefly those traveled by writer).
Roads passable for wheeled vehicles.
Prominent peaks and hilltops.
Escarpment. * Small hill.
CHIHUAHUA
SONORA
Mesa de San Augustín
Mesa de Venado
2200 - 2400
Río de Haros
Arroyo Cuevitas
Dolores
1600
Amplio
1190
Tv
Tbu
Arroyo Granados
1520
Ks
Agua Caliente
1300
Río Tutuaca
Los Animas
Río Yepachic
Yepáchic
2060
CERRO BOLUDO
2400
San Francisco
1780
Paraqatos
Aglomerate
Las Arañas
Andesite
El Pinito
Temóchic
2110
Río Arañas
La Cueva Chumeda
Agua Caliente
Cumbre Potrero
2120
Pinos Altos
2410
Rhyolite
Caracol
Pueblo Viejo
El Capirín
El Durazno
La Cienaguita
El Durazno de Tello
El Potrerito
El Rosario
CAMPO
1732
Las Gallinas
Andesite
Cascada de Basaseachic
Río Candameno
Conglomerate Mesa
Casa Blanca
C. PILAR
La Ciénega
Socorro
SA. DE LA TROMPA
Río Dolores
Las Manzanas
Arrecuipa
Basaseachic
Tapiliillas
Tascate
La Cumbre
Uruachic
C. EL GACHUPÍN
Concepción de Arriba
LA FISHERSA
Batagachic
San Isidro
Las Trojes
Bocoybeachic
Recamdrachic
La Joya
SIERRA DE GUICHUICHIC
Río de Oteros
Ocobiachic
CHARUCO
E'
La Ciénega
Agua Caliente
CHINIPAS
El Zapote
Río Chinipas
Cuiteco
Churo
2270

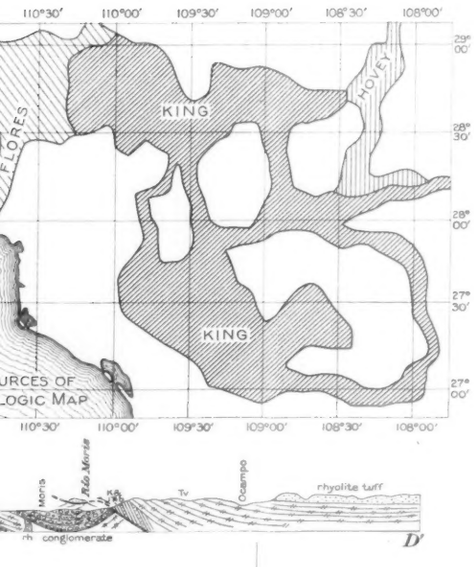
28°
IV
27° 30′
V
27° 00′
VI
Batamotal
Empalme
Piedra
16
GUAYMAS
CERRO TORDILLO
179
Guásimas
Mapoli
CABO HARO
▲503
▲368
Tv
Tbl
Qaj
GULF OF CALIFORNIA
DE BACATETE
Río Muerto
Oroz
Pótam
16
Lencho
23
Jori
28
RÍO YAQUI
COASTAL
Qaj
ESTERO DE LOBOS
PUNTA LOBOS
IRRIGATION CANAL
Sierra del Aguaje
Sierra de la Colorada
Arroyo de Mariposa
Cerro León
Cerro Cobachi
A
Cerro del Carrizal
Sierra Cañón de Ugalamas
Sierra de Moradillas
Cerro Colorado
Cerros de Sanguijuela
C. la Cuesta
C
Río Yaqui
D
GEOLOGIC DRAFTING BY LEWIS B. PUSEY
111° 00′
A
110° 30′
B

RECO

110°00′ C 109°30′ D

RECONNAISSANCE GEOLOGIC MAP OF PART OF THE SIERRA
OF SONORA AND CHIHUAHUA,

Picacho de la Chuma
SIERRA DE SAN LUIS
CERRO ZARAPEROS
CERRO PUERTO
Río Mayo
Arroyo Guayparín
Arroyo Cedros
Arroyo Cuchujaqui
Arroyo Frijol
Arroyo Capadero
Arroyo Cuchujaqui
Arroyo Los Ajos
Arroyo Los Ajos
Arroyo Los Ajos



RECONNAISSANCE GEOLOGIC MAP OF PART OF THE SIERRA MADRE OCCIDENTAL IN THE STATES OF SONORA AND CHIHUAHUA, MEXICO

SURVEYED IN 1932-1933

BY ROBERT E. KING

WITH SOME ADDITIONAL INFORMATION FROM TEODORO FLORES AND E. O. HOVEY AS SHOWN ON THE INSET MAP

0 5 10 15 20 25 30 KILOMETERS

0 5 10 15 20 25 30 MILES

1939

Geographic base in colored areas is largely from compass traverses by the author, adjusted to fixed points on the official Mexican state maps. These maps have also been consulted for geographic data between the traverses.

Elevations on the map are in meters, and are from a variety of sources. Those away from the railroad lines are probably approximate only.

Sections approximately follow lines on map

108°30' F 108°00' G

THE STATES

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 50, PP. 1625-1722, 9 PLS., 7 FIGS. NOVEMBER 1, 1939

GEOLOGICAL RECONNAISSANCE IN NORTHERN SIERRA MADRE OCCIDENTAL OF MEXICO

BY ROBERT E. KING

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INTRODUCTION

GENERAL STATEMENT

The crests of the Sierra Madre Occidental, in the western part of Mexico, form the boundary between the west coast States of Sonora and Sinaloa and the interior States of Chihuahua and Durango. These plateau-like crests, carved from gently inclined volcanic rocks, are in contrast to the Sierra Madre Oriental, in eastern Mexico, which consists for the most part of parallel ridges carved from folded sedimentary rocks.

The western Sierra Madre takes form south of the International Boundary by the coalescing of mountain ranges which in southern New Mexico and Arizona are more or less isolated. South of the boundary, the plains between the mountains become narrower, and the volcanic rocks spread out in a broad plateau. The western edge of the plateau, at an elevation of 6000 feet or more, breaks off toward the Gulf of California in lofty escarpments (Pl. 2), which are trenched by most impressive gorges. West of the Sierra Madre proper high ranges are separated by long, narrow valleys. In central and western Sonora low mountains are separated by broad plains, as in the Basin and Range province of southwestern United States.

Little has been written on the geology of the western Sierra Madre in eastern Sonora and western Chihuahua. Travelers tell of the rugged beauty of its ranges and canyons, the geology of some of the mining camps has been examined, and a few traverses have been made. The range has been generally assumed to be a structurally simple plateau of flat-lying lavas overlying an eroded basement of sedimentary rocks and ancient granites.

The present paper purports to give a more detailed picture of the geology of the western Sierra Madre. It is based in part on the work of others, but to a much greater extent on unpublished original observations. Although these observations are not complete, they reveal a far greater complexity of geologic history than earlier work suggested.

The approximate ages of the older sedimentary rocks have been determined, and the volcanic rocks have been found to belong to at least two structurally discordant groups. The granites, formerly assigned in large part to the basement complex, are mainly middle Tertiary. The lavas, although only gently tilted over wide areas, are elsewhere folded and overthrust. An extensive series of intermontane deposits, laid down after the mountains had begun to assume their present outlines, are shown to have since been folded and faulted. The region is thus one of eventful geologic history, in which compressive forces have acted until relatively late in geologic time.

PREVIOUS WORK

The first geological studies in the region were made by Rémond (1866). He described the characteristics of the Barranca formation and collected Upper Triassic plants and invertebrates from the region of San Marcial and San Javier, and Lower Cretaceous invertebrates from east of Arivechi. He also reported Carboniferous limestones east of Hermosillo. The invertebrate fossils collected by Rémond were described by Gabb (1864; 1869). Aguilera (1896-1897) made several traverses in Sonora and revisited Rémond's localities.

In 1894 and 1895 McGee and Johnson (1896) visited the country of the Seri Indians on the coast of the Gulf of California west of the area of this paper. The purpose of the expedition was chiefly a study of the ethnology, but some notes on the bedrock geology and important observations on the geomorphology were made. McGee's (1896; 1897) observations on the desert mountains and the rock-cut plains or pediments around them, and on the action of sheet floods, have helped to lay a foundation for modern conceptions of desert land forms as developed in the Southwest. The excellent topographic map of the district by Johnson shows features typical of wide areas in western Sonora.

In 1898, Dumble (1900a; 1900b; 1901a; 1901b) made a geological reconnaissance in central and southeastern Sonora. He was the first to recognize the presence of Paleozoic rocks and to define the Barranca formation as a stratigraphic unit of Triassic age. Much of the structural complexity of the region was, however, not recognized by him, and some of his age determinations have since proved incorrect.

In 1904, Angermann discussed the results of a brief trip to the Cedros valley north of Álamos. He attempted to find some fossiliferous Paleozoic rocks, reported by Dumble near a place called Casita, but fell into the natural error of supposing that this was a ranch on the Río Cedros which is shown on most maps of the State. Actually, Dumble's Casita locality is much farther north, in the northern part of the area described in the present paper, and is shown on few maps.

In 1907, Hovey described the geologic features observed during a reconnaissance in western Chihuahua. The traverse was hurried, but important observations were made, so that the paper is still the principal source of reference for that part of Chihuahua. Most of the traverse was in the plateau region, so that one receives few hints of the structural complexity of that part of the Sierra Madre west of the plateau.

Numerous articles in trade journals discuss mining districts of the region but refer mainly to geography, technology, and production. Several, however, contain valuable geological notes on the Chínipas, Ocampo,

Sahuayacán, and Lluvia de Oro camps of western Chihuahua and have been included in the bibliography. Some of the graphite deposits near La Colorada, Sonora, have also been described by Hess (1909).

The only important geological description of central Sonora since Dumble's time is that of Flores (1929). He examined a strip along both sides of the Ferrocarril Sud-Pacífico from Nogales to Guaymas and made detailed studies of some of the mining districts. He gave special attention to economic geology; the rock units distinguished on his maps are largely lithologic; and in only a few places are their ages determined accurately.

FIELD WORK AND ACKNOWLEDGMENTS

The area described in the present paper lies between 108° and 111° W. long. and 27° and 29° N. lat. (Fig. 1). The writer first became interested in the region in 1931, when he went to Sonora to investigate the Paleozoic strata reported there by Dumble. As the complexity of the geology became evident, the work widened in scope to include sedimentary and igneous rocks of other ages, as well as geomorphology and structure. Field work was carried on intermittently during 1932 and continuously for 6 months in 1933. The first field work was in central Sonora southeast from Hermosillo as far as the Río Yaqui, and in the district of Álamos. The later field work was between Álamos and the Río Yaqui on the west and the crest of the high Sierra Madre of western Chihuahua on the east.

During the earlier phases of the work, the writer was aided financially by Professor Charles Schuchert of Yale University. The work in 1933 was carried on under a grant from the Penrose Bequest of the Geological Society of America.

The geologic map (Pl. 1) was constructed from pace traverses made on horseback or afoot, supplemented by compass triangulation. The northern part of the area was studied in most detail and forms a cross section of the western Sierra Madre and the ranges bordering it on the west. Much of the remainder of the area was crossed by widely spaced traverses in various directions. Even in the regions on which most time was spent, some of the geologic mapping was of necessity done by sketching distant points. Between the traverses, even more hypothetical geological boundaries have been sketched in, in order to show more clearly the inferred broader geologic features.

In the extreme western part of the area, much mapping was taken from Flores' work, with some revision and the addition of age assignments to the rocks. Hovey's traverse crossed the northeast corner of the present map area. No detailed map of the route was published by Hovey, but for completeness the writer has plotted his geological

observations and formation boundaries on the map, using the official Mexican base maps for location.

Field work was carried out under difficulties but was greatly aided

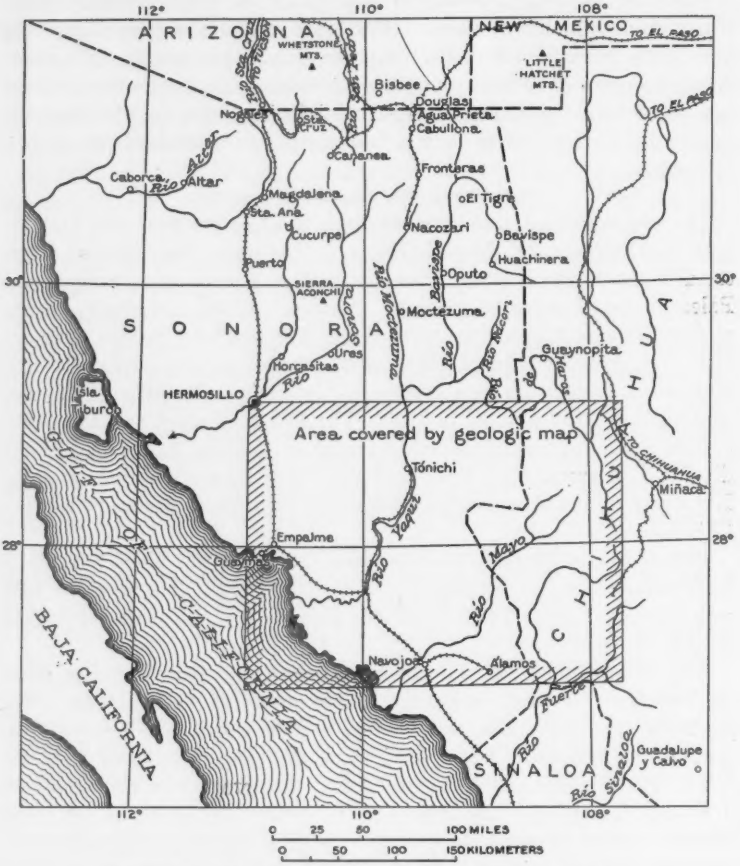


FIGURE 1.—*Sketch map of Sonora and adjacent territory*

Shows area described in this paper and localities mentioned in the text that are outside the limits of Plate 1.

by the hospitality of the people and the cordiality of the managers of the mines. Because of the difficulties of travel in the region, only small loads could be carried while making the traverses. It was, therefore, not always possible to photograph impressive views or important exposures, nor could more than a few specimens of the igneous rocks be collected.

The fossil collections are also small, but this is chiefly because the rocks are barren except at a few localities.

Because of the large area covered and the unfavorable conditions for field work, the investigation can best be classed as a reconnaissance. However, the writer believes that he has visited enough critical localities to place the main conclusions on a relatively firm basis. It is hoped that some other geologist will undertake a careful study of the intrusive and volcanic rocks. Many problems would also be cleared up by a reconnaissance geological study of that part of Sonora between the Sahuaripa district, at the northern end of the area mapped, and the Nacozari district (Fig. 1).

The fossils collected during the investigation have been studied by various specialists. The fusulinids were examined by Professor C. O. Dunbar of Yale University, and the Triassic plants by Dr. C. B. Read of the United States Geological Survey. The Cretaceous fossils were studied by Mr. W. S. Adkins, at that time with the Texas Bureau of Economic Geology. The small collection of igneous rocks was studied by Mr. Ward Smith of Yale University.

Unpublished observations on regions adjoining that studied have been generously furnished by Mr. Robert D. Butler and Mr. Charles Laurence Baker. The manuscript was edited and criticised in detail by Dr. Philip B. King, who also aided in planning the illustrations. The excellent drafting of the maps and sections was done by Mr. Lewis B. Pusey of the staff of the United States Geological Survey. The writer is indebted Dr. Ralph W. Imlay for permission to read his interesting paper on "Paleogeographic studies in northeastern Sonora" in advance of publication.

GEOMORPHOLOGY

GENERAL STATEMENT

The area studied may be divided into three geomorphic provinces, which have a northward elongation (Pl. 2).

SIERRA MADRE OCCIDENTAL PROVINCE

Definition.—The Sierra Madre Occidental province has been defined by Brand (1937, p. 11) as

> "a great plateau of extrusives, having NNW-SSE narrow structural depressions between smooth-topped ridges, mesas, and minor plateaus, and segmented by the gorges of transverse antecedent or headward-eroding streams flowing through deep gorges to the Pacific lowlands".

North of lat. 29° N. is largely a plateau surface, which has been described in detail by Brand (1937, p. 28-33). From the gorge of the Río de Haros southward, the western margin of the province is deeply incised

by the barrancas or gorges of streams draining to the Pacific (Pl. 2). As a result of this, the province is divisible in the area studied by the writer into two distinct parts—the eastern or plateau section and the western or barranca section.

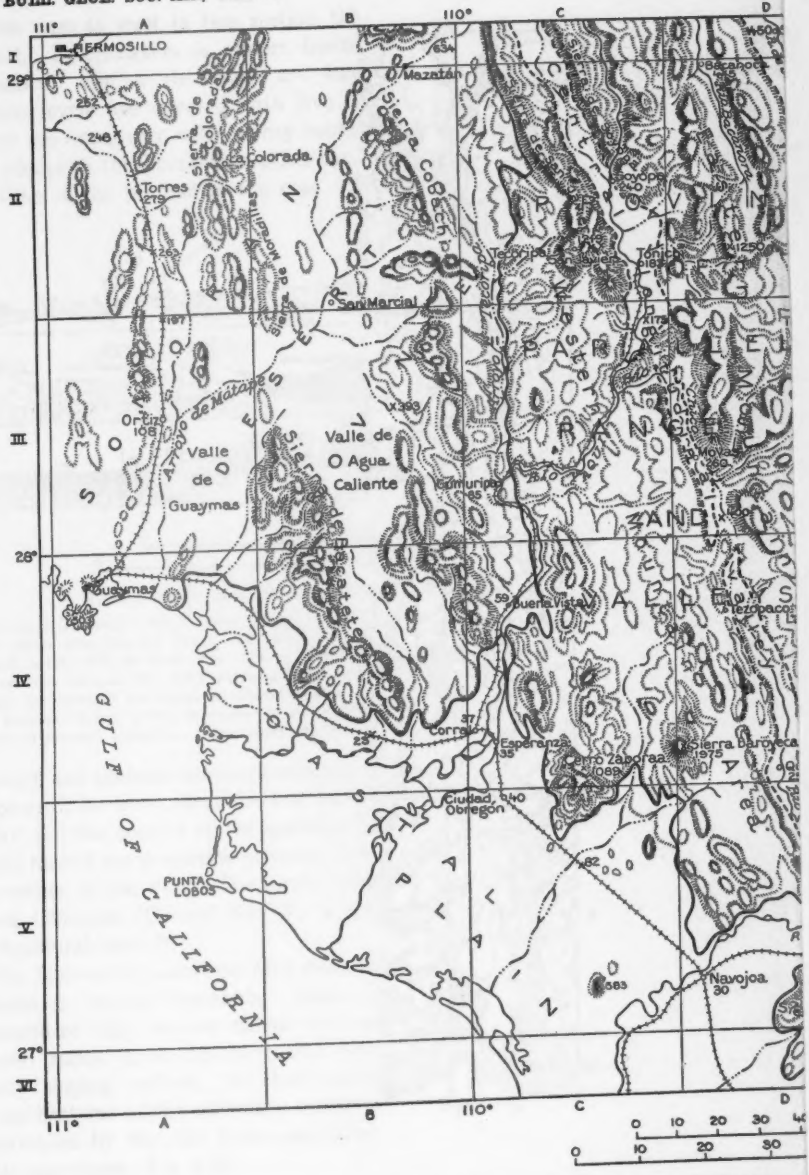
Plateau section.—This section has a gently rolling surface carved from lava flows and associated pyroclastic rocks and conglomerates. Irregular mountainous areas stand at altitudes of 6600 to 8500 feet and are separated by broad, flat-bottomed, and, in part, marshy valleys. Most of these are drained by tributaries of the Yaqui, Mayo, and Fuerte rivers, which downstream flow through the deep gorges of the barranca section toward the Pacific; others are bolsons. The head streams have a dendritic pattern and meander in broad valleys. The characteristic vegetation of this section is pine and oak forest.

Toward the west, the summit levels do not increase in height, but the relief becomes progressively greater, because the region is profoundly dissected by streams draining to the southwest. The western border of the plateau surface is extremely irregular. Long tongues of it project westward between the major streams, and these, becoming intrenched deeper and deeper, at last form great barrancas.

In places, the fall of the streams from the plateau is abrupt. Thus, east of Ocampo and 2 miles south of the village of Basaseáchic (Co-ord F-III),[1] the Río Durazno leaves a high-level marshy valley between low, pine-clad ridges and rushes over a vertical fall 980 feet high, carved from massive rhyolite tuff (Self, 1894). Below the fall the river flows in a narrow, vertical-walled gorge in the tuff (Pl. 3). This sharp break in topography marks the boundary between the mature erosion surface of the plateau section and a region of youthful topography to the west, whose base level lies thousands of feet lower.

Barranca section.—West of the break in topography a belt of deeply dissected country 25 to 60 miles wide (Pl. 2) is also composed for the most part of gently tilted lava flows, but the streams, which flow southwestward to the Gulf of California, have developed a youthful topography. A few remnants of flat ground on the high interstream divides give proof of the former extension westward of the mature surface which is still unbroken in the plateau section to the east. The major southwest-flowing streams, as a result of the general downcutting of the area, have carved out tremendous barrancas (Pl. 4, fig. 2), some of which reach 6600 feet in depth. Since these are the most characteristic features of this belt of country, the area is here termed the "barranca section."

[1] This and co-ordinates hereinafter noted refer to figures on the margins of Plates 1, 2, and 9.



RELIEF MAP SHOWING BOUNDARIES O

Heights in mete

RELIEF MAP SHOWING BOUNDA

Height

BOUNDARIES OF GEOMORPHIC PROVINCES

Heights in meters

From east to west in this section there is a progressive decrease in rainfall. Precipitation is almost limited to the period from June to December. Higher elevations are forested with large pines. Intermediate levels are covered with live oaks, and the lower slopes and valleys are overgrown with thorny brush, including giant cacti.

In places in the barranca section the geologic structure is more complex than in the plateau to the east. Faults have raised belts of sedi-

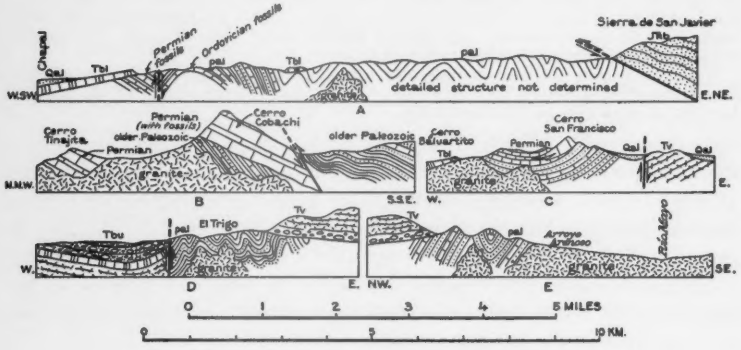


FIGURE 2.—*Sections showing structure and stratigraphy*

Outcrops of Paleozoic rocks in central Sonora.

(A) Casita area (Co-ord C-II). (B) Cerro Cobachi area (Co-ord B-II). (C) Zubiate area (Co-ord A-II). (D) El Trigo area (Co-ord D-IV). (E) Arroyo Arenoso area (Co-ord D&E-V). The relations between the older Paleozoic rocks and the Permian on the north side of Cerro Cobachi in Figure B are based on Dumble's observations and were not verified by the writer. (pal) Paleozoic rocks; (JTrb) Barranca formation; (Tv) early Tertiary volcanic rocks; (Tbl) lower member of Báucarit formation; (Tbu) upper member of Báucarit formation; (Qal) alluvium.

mentary and plutonic igneous rocks into the zone of erosion (Pl. 4, fig. 1). In general, however, structure has had only a minor effect on the topography and the control of the drainage lines. Many of the ridges in the region have a north-northwest trend, but this is much less regular than in the ranges to the west. The north-northwest trend of the Río Chínipas below Chínipas (Co-ord E&F-V) is striking but may not be a result of structural control.

The high-level mature surface from which the region has been carved persists in various remnants. Most of these are small areas on the summits of high, narrow ridges and ramifying spurs. Some remnants several miles across are pine-clad rounded ridges, separated by flat, gently sloping valleys. At their edges the land slopes steeply down to the bottoms of the adjoining barrancas, in places descending in steps determined by rhyolite flows and other resistant members of the volcanic succession (Fig. 6-B).

Examples of smaller remnants of the high-level surface may be seen at El Pilar and La Ciénaga west of Moris (Co-ord E-III), Arechuybo (Co-ord E-IV), Ocóbiachic between Uruáchic and Cuiteco (Co-ord F-IV), and El Manzano and La Cieneguita between Urique and Lluvia de Oro (Co-ord G-V). West of Chínipas (Co-ord E-V), on the boundary between Sonora and Chihuahua, an area of low relief on the summit of a steep-sided range has a width of over 4 miles in its southern part but narrows to the north.

The most extensive areas of high-level remnants are north of the east-west segment of the Sonora-Chihuahua boundary near Yécora (Co-ord E-III). At Yécora the surface is intact over an area of 7½ square miles and is a flat plain mantled by alluvium, from which a long dip slope on the surface of the lavas rises southward to the State line. Farther north, 6 miles west-northwest of Taráchic, a basin of low relief at Agua Blanca (Co-ord D-II) stands nearly 1000 feet higher than the other remnants. It may represent an erosion surface older than the rest or may be controlled by an underlying bed of resistant lava.

North of Yécora the principal streams flow northward. South of Yécora streams flowing southward to the Río Mayo have a relatively direct course to the sea and have cut gorges 3000 to 6600 feet deep.

At most places in the barranca section the benches on the slopes below the high-level surface are determined by resistant lavas, as at Babanore (Co-ord E-III). Locally, however, there seems to be evidence for erosion surfaces younger than the high-level surface. Benches and flat areas, in part mantled by alluvium and carved from apparently homogeneous rocks, are found at levels below the higher surface, and in some of the barrancas the upper slopes are gentler. Remnants of aggraded terraces were not seen in the barranca section.

Near Uruáchic (Co-ord F-IV) there is evidence for four cycles of downcutting. On the mountain slopes above Uruáchic, but below the high-level surface, are several sloping benches which are apparently erosion remnants of the second cycle. The valleys below them near Uruáchic, flanked by high hills, have narrow flood plains and small meandering streams and were probably formed in the third cycle. The stream gradient below Uruáchic increases sharply, and a narrow inner gorge has been cut, probably in a fourth cycle, in a valley whose upper slopes are gentle and rounded.

Four miles north of Urique (Co-ord G-V) are two distinct levels of flat-topped mesas, thinly sheeted by alluvium and carved from massive andesite. They lie about 325 feet apart vertically and have a general elevation of about 4900 feet.

Along the Río de Tubares below Tubares (Co-ord F&G-VI) are rock-cut terraces which may have been formed by lateral cutting during the normal process of valley development.

At a number of places well-developed entrenched meanders may be seen in the deep gorge of the Río Babanore (Co-ord E-III), near Batopilillas on the small Río Batopilillas (Co-ord F-IV), south of Uruáchic on the Río de Oteros (Co-ord F-IV), on the Río de Urique near Urique (Co-ord G-V), and on the Río de Tubares (Co-ord F-VI). Near Chínipas (Co-ord E-V) the deep gorge of the Río Chínipas makes several broad, terraced loops; similar features are seen on the Río Mayo (Co-ord E-IV).

The barranca section gives place westward near the 109th meridian to a region of parallel ranges and valleys, above which it generally rises in a more or less continuous line of high, west-facing escarpments (Pl. 2). The region to the west is one of greater structural complexity, and the topographic features of the barranca section, determined largely by the profound erosion of a plateau-like area, are replaced by a topography in which the ridges and valleys follow the major structural trends.

The escarpment along the western edge of the barranca section has in many places been elevated by faulting above the longitudinal valley which flanks it on the west. The escarpment rises to its greatest height east of the valley of Sahuaripa (Co-ord D-II), where it culminates in the rhyolite-capped Cerro San Ignacio, whose elevation may reach 6600 feet (Fig. 4). Here, the high, east-sloping country east of the scarp has low relief but is drained by west-flowing streams which increase abruptly in gradient toward the scarp, where they are deeply incised. This may be due to recent upfaulting of the escarpment.

In the north, the western margin of the barranca section of the Sierra Madre Occidental province does not coincide with the western margin of the province as outlined by Brand (1937, Map 3), who places the line of division parallel to and a few miles west of the Sonora-Chihuahua State line as far south as lat. 28°30′ N. The writer believes that the dividing line probably trends northeastward from the mouth of the Río de Sahuaripa in the Río Yaqui, following the eastern side of the Nácori-Huachinera-Bavispe depression (Fig. 1). About 10 miles south of the 31st parallel, the Sierra Madre Occidental province terminates, with the Mexican Basin and Range province and the province of parallel ranges and valleys meeting at its northern end.

PROVINCE OF PARALLEL RANGES AND VALLEYS

A belt 55 to 75 miles wide of longitudinal mountain ranges which are separated and paralleled by less extensive intermontane valleys is here called the province of parallel ranges and valleys. The average trend of both ranges and valleys is N. 10° W.

The rainfall of the region is scanty and intermittent. From the end of June until November there are periodic rains. In the latter part of November there are generally all-day rains, or *equipatas*, which supply the water needed for sowing wheat. The water level of the rivers is low during the early part of February, but later in the month there are floods caused by melting of the snow in the high Sierra Madre. In the extreme dry period of June even the Ríos Yaqui and Mayo are hardly more than chains of pools separated by dry gravel beds.

The vegetation of the province varies greatly according to the altitude. Pines grow in only a few of the highest ranges; most of the higher summits are covered with oaks; the lower slopes bear a dense growth of thorny bush, of which mezquite and giant cacti are most conspicuous. In some of the sheltered valleys of the western sides of the ranges groves of palms are surrounded by grassy savannas with scattered oak trees.

Although the land forms and structure of the province are very complex in detail, it is possible to distinguish a longitudinal valley along the

eastern border and another separating the mountain area into two main subdivisions (Pl. 2). The western ranges of the province decrease in height toward the south, and near the Ferrocarril Sud-Pacífico many of them pitch beneath the coastal plain.

The mountains are interpreted as upfaulted blocks. In the north most of the faults are upthrown on the east, producing steep west-facing escarpments and more gentle eastward slopes. The ranges are composed of older quartzites and limestones, capped by lavas similar to those in the Sierra Madre province. These are intruded by granite and other plutonic rocks. The valleys are underlain by gently folded late Tertiary conglomerates (Báucarit formation). In the south, where the valleys are wider, basalts interbedded in the Tertiary conglomerates rise in low mountain ranges.

The most resistant rocks in the mountains are the lava flows. In places these are flat-lying or gently tilted and form mesas with terraced slopes as in the Sierra Madre province. Some of the thick rhyolite flows are cut into high, sheer pinnacles, as in the Sierras de Álamos (Co-ord D-V&VI) and Baroyeca (Co-ord C&D-IV). The limestones form bold, bare peaks, though not so high as the lava ridges. The plutonic rocks are generally eroded to low pediments.

Planing of the late Tertiary conglomerates, as well as the plutonic rocks, to pediments is the immediate cause of most of the intermontane valleys. In places where recent uplift has been greater, the conglomerates are carved into pinnacled bluffs (Pl. 8, fig. 2), steep-sided buttes, and pillars, separated by slot-like gorges, as at Los Pilares east of Tónichi (Co-ord D-II). Some form the summits of high ridges, as at La Palma and Guaycora (Co-ord D-II). On the eastern slopes of some of the ranges, stream-scalloped hogbacks and cuestas are formed by basalt flows interbedded in the lower part of the late Tertiary conglomerates. On mountain slopes above the cuestas, basalt outliers rise as steep-sided buttes, as west of El Valle de Tacupeto (Co-ord D-II).

The Ríos Yaqui and Mayo flow diagonally across the province southwestward to the Gulf of California (Pl. 2). In most places they show no close structural control. The Río Mayo flows across a broad granite pediment area below the mouth of the Guajaray and crosses transversely the central longitudinal valley. The Yaqui flows directly across the central mountain area to Soyopa, down the central longitudinal valley to La Dura, and then winds across the western mountain area, in places flowing on soft conglomerate and in others crossing ridges of quartzite and lava in deep, narrow gorges (Pl. 1). At the great loop at Cumuripa, it twice crosses a belt of the late Tertiary conglomerate which flanks the

GORGE OF RÍO CANDAMEÑA BELOW CASCADA DE BASASEÁCHIC (CO-ORD F-III)
Walls of gorge are formed of massive rhyolite tuff.

FIGURE 1. RIDGES SOUTHEAST OF LA TROMPA AND NORTH OF RÍO MAYO
(Co-ord E-IV)
View northwest toward northeastward-dipping beds of Tertiary agglomerate and other volcanic rocks, overlain in right foreground by Cretaceous limestone that crops out in white crags, and which has been overthrust upon the volcanic rocks.

FIGURE 2. RUGGED TOPOGRAPHY CARVED FROM TERTIARY VOLCANIC ROCKS
Gorge of Río de Tubares, as seen from Lluvia de Oro (Co-ord F-VI). Cretaceous limestone exposed in cliffs in left foreground.

BARRANCA SECTION OF SIERRA MADRE OCCIDENTAL PROVINCE

western edge of the province and intersects it again at Buena Vista farther south.

Most of the larger tributary streams follow the longitudinal valleys and reduce the late Tertiary conglomerates to sloping pediments. An exception is the Río Chico (Co-ord C&D-III), which enters the central longitudinal valley from the east near Movas, follows the valley northward for 13 miles, then trenches a mountain uplift to reach the Río Yaqui.

In the northern part of the area studied the eastern longitudinal valley is followed by the Río de Sahuaripa, an intermittent stream with several stretches up to a few miles in length in which surface flow is constant. The Sahuaripa and its larger tributaries have a narrow flood plain, entrenched about 65 feet in a pediment which slopes gently from the mountains on each side. North of El Valle de Tacupeto (Co-ord D-II) there are narrow but fertile *vegas* of alluvial soil along the stream.

The eastern mountain area of the province is split in the north by the narrow longitudinal valley of the Río Bacanora, in part carved from late Tertiary conglomerates. Near the head of the Bacanora valley, at El Encinal and Milpillas (Co-ord D-II), the land has comparatively low relief and may be the same erosion surface as that on the plateau summits in the Sierra Madre province farther east. South of Los Pilares, the conglomerates and basalts cover much of the area and stand in long narrow mesas and cuestas. The crest of the eastern range is composed chiefly of older lavas which stand in high stratified mesas, while the crest of the western range consists of sharp ridges of quartzite and limestone and is flanked in places on the west by granite pediments.

South of the 28th parallel the eastern mountain area is largely late Tertiary basalt. The separate ranges are united into a broad mass of rounded ridges trenched by deep arroyos. Southeast of Quiriego, between the Río Cedros and Arroyo Guajaray, a steep-sided range is carved from older lavas and is flanked on the east by granite pediments. Southeast of the Río Mayo in the eastern mountain area only low hills rise from the granite pediment.

West of the eastern mountain area is a discontinuous, narrow, longitudinal valley carved from the late Tertiary conglomerates and basalts. From Rebeico to La Dura (Co-ord C-II&III) it is 2 to 5 miles wide and except at its northern end above Soyopa is followed by the Río Yaqui (Pl. 2). The conglomerates of the valley have been worn down to pediments, above which rise hogbacks of basalt, and into which the winding Río Yaqui has been entrenched about 150 feet. The flood plain of the Yaqui is relatively narrow, but at Ónavas (Co-ord C-III) fertile alluvial terraces lie between the river level and the pediment surface. A lobe of quartzite hills projecting from the eastern mountains south of La Dura (Co-ord C-III) separates the Rebeico-La Dura segment of the valley from a southern portion, which extends from Río Chico to south of Movas (Co-ord C&D-III). The Río Cedros follows the northern portion of another valley on the strike of that at Movas, but separated from it by hills of lava. East of Álamos, the southeastward continuation of this valley is a broad area of low hills and mesas carved from conglomerate.

West of the central longitudinal valley a second belt of mountains forms the western part of the province (Pl. 2). In the north, west of the Río Yaqui, is the high range of the Sierra de San Javier, 12 miles wide, composed largely of quartzite which rises in sharp peaks (Pl. 8, fig. 1). This high range terminates south of San Javier, and from there south to the Río Yaqui are irregular ranges composed principally of volcanic rocks, separated by narrow pediments of granite and conglomerate. Southeast of the Yaqui, several parallel ranges and valleys lie between the intermontane valley of the Río Cedros and the coastal plain. The ranges are generally lower than those to the north, owing to the southward pitch of the structural features. Where composed of late Tertiary basalts, these are low and rounded, or of cuesta-like form, but in places underlying rhyolites and some associated sedimentary rocks rise higher than elsewhere, and in the Sierra de Baroyeca there are high pinnacled crests. In places on the flanks of the ranges, pediments carved from granites occupy wide areas. The longitudinal valleys are underlain by late Tertiary conglomerates. To the south, as the ranges pitch lower, basalt occupies a wider area, and the alluvial flats of the coastal plain extend around and between the mountains.

North of the coastal plain, the western border of the province of parallel ranges and valleys is a longitudinal intermontane valley, parts of which have been noted above, which extends from Mazatán to Buena Vista. The boundary marks a westward change from a region of high, parallel, more or less continuous mountain chains with subordinate intermontane lowlands to one of wide plains and lower mountain ranges.

SONORAN DESERT PROVINCE

The Sonoran desert province is an arid region extending from the western base of the Sierra de San Javier and ranges to the south of it, westward to the Gulf of California. Similar country also extends northwestward into the Pápago country of southwestern Arizona. The region has been well characterized as follows by McGee (1897, p. 89-91):

> "To the casual observer traversing its expanse, it seems a region of mountains, for rugged buttes, mesas, and sierras are always in sight and usually dominate the landscape; but more careful observation shows that it is primarily a plains region. . . . At first sight the . . . district appears to be one of half-buried mountains, with broad alluvial plains rising far up their flanks, and so strong is this impression on one fresh from humid lands that he finds it difficult to trust his senses when he perceives that much of the valley-plain area is not alluvium, but planed rock similar to or identical with that constituting the mountains. To the student of geomorphology this is the striking characteristic of the Sonoran region—the mountains rise from the plains, but both mountain and plain (in large part) are carved out of the same rocks. The valley interiors and the lower lowland areas are, indeed, built of torrent-laid debris, yet most of the valley area carries but a veneer of alluvium so thin that it may be shifted by a single great storm. Classed by surface, one-fifth of the area of the Sonoran district . . . is mountain, four-fifths plain; but of the plain something like one-half, or two-fifths of the entire area, is planed rock, leaving only a fraction of thin alluvium."

The mountain ranges of the area form disconnected ridges, many without definite alignment (Pl. 2), due in part to profound erosion, which has worn down their weaker rocks to the rock-cut plains described by McGee. Some former mountain areas thus remain only as scattered steep-sided erosion remnants, or *inselberge*. Some of the mountain ranges retain vestiges of an original fault-block form. Thus, several north-south-trending ranges south of La Colorada, such as the Sierra de Moradillas (Co-ord B-II), have on their western side a cuesta-like, westward-tilted capping of lavas, and on the east a greatly dissected face of older rocks. A few of the mountains have been uplifted in relatively recent times by such faulting, and in such places they are fringed not by the usual rock-cut pediments but by alluvial fans, excellently displayed along the eastern fault scarp of the Sierra de Cobachi.

The sloping, rock-cut plains described by McGee, now generally known as pediments or rock floors, are chiefly carved from granites but in places are mantled by lava flows or thinly masked by alluvium.

Several different levels of pediments have been observed in the area but they were not studied in detail. In the vicinity of Suaqui Grande

(Co-ord C-III), possible remnants of an old surface form benches around the hills 650 feet or more above the present streams. The main pediment here is 225 feet above the present streams but slopes upward toward the bases of the high ranges. The town of Suaqui Grande lies on a still lower but less extensive pediment. The main pediment of the Suaqui Grande area appears to extend over the entire region, with varying elevation above the present streams. It is covered in most places by detritus, but locally this is only a few feet thick. In the broad valley north of Tecoripa toward Mazatán (Co-ord B&C-II), the detrital cover is much thicker, and later dissection by streams has only in places revealed the bedrock.

Farther west, on the east side of the Sierra de Moradillas (Co-ord B-II), Flores (1929, Pl. 7) shows in a diagram the granite bench or mesa of Sal Si Puedes. This seems almost certainly to be a remnant of a high-level pediment fringing the base of the mountains.

The main rains of the year are from July until September, with occasional later ones until January. A three-year record for Hermosillo shows a precipitation of 3.02 inches per year, all concentrated between July and January, with a maximum in August and September. In Guaymas a three-year average is 9.6 inches. (*See* Anonymous, 1924, p. 373.) The desert flora of the area consists mostly of grass, thorny trees, and cacti, including mezquite, ironwood, sahuaro, pitahaya, and cholla.

The general character of the streams and drainage in the Sonoran desert has been well described by McGee (1897, p. 97-98):

> "In the sierras the permanent streams are slender threads of water slipping over ledges, now gathering in tinajas, and again disappearing in fissures or gravel pockets at the bottoms of the rugged barrancas. . . . Most of the multitudinous barrancas are supplied only by storm torrents, and these usually end about the base of the sierra; it is only the deeper and longer barrancas that send arroyos or permanent channels far enough over the plain to unite with other water ways in dendritic systems. . . . Outside the sierras the typical channel is at first a rugged or flat-bottomed barranca cut in the country rock; it soon diminishes in depth and increases in width and becomes lined with boulder beds; still further down stream it changes into a broad, steep-banked arroyo cut in alluvium and burdened with gravel beds or sand sheets.
>
> "The ground water is of considerable importance as a source of streams, partly since its flow is moderately steady, and its tendency is thus to maintain the stream throughout the year. In the mountain gorges the ground water commonly emerges as permanent or temporary springs, while in the alluvium-lined valleys it simply seeps through the sand, generally below the surface, though sometimes in a slender streamlet winding through the broad sand wash. . . . So it happens that water may often be found by digging in the dry sands of a wash; that a nominally permanent stream may appear, disappear, and reappear half a dozen times in the course of a day's journey down a wash, and that the rippling streamlets lengthen during the night and in cool or cloudy weather, and shrink during the day and the heat, when evaporation culminates."

The two main streams of the area are the Arroyo de Mátape and the Río de Sonora. The latter drains a wide area (Fig. 1), and its persistence is due largely to the fact that most of its water comes from the

mountainous region east of the Sonoran desert. It carries a great volume of water in the mountains north of Ures, but near Ures much water is drawn off for irrigation. South of this town it flows southwestward across the ranges and structural trends of the Sonoran desert. Upon reaching Hermosillo all the remaining dry-season flow is used for irrigation. From there to the coast, where it ends in a small inlet, the Río de Sonora consists of numerous anastomosing channels which are dry except in flood times (McGee and Johnson, 1896, Pl. 4).

The Arroyo de Mátape drains a broad expanse (Pl. 2), but as it lies in the Sonoran desert the stream is generally dry. There are permanent *aguajes* at Cobachi, San José de Pimas, San Marcial, and Punta de Agua at the northern end of the Sierra de Bacatete (Co-ord B-II & III). Between these stretches, water does not flow except following rains, and flowing water rarely reaches the mouth of the arroyo in the Gulf of California, near Empalme (Co-ord A-IV).

Relatively recent changes in the position of the shore line of the Gulf of California west and south of the area studied have been reported. Dumble (1900a, p. 125) described raised beaches in the Valle de Guaymas, extending within 9 miles of Ortiz (Co-ord A-III). McGee and Johnson (1896, p. 128) note that the Desierto Encinas, the first desert valley east of the coast in the latitude of Isla Tiburón (Fig. 1), is

> "lined in its lower levels by a sheet of sediment charged with recent marine shells, which show that at no remote day it was an arm of the sea."

These same observers, however, note that El Infiernillo, the strait which separates Isla Tiburón from the mainland, fills the center of an intermontane depression whose land forms, while slightly modified by marine erosion, do not otherwise differ from those of the neighboring subaerial desert valleys. They suggest that this indicates a recent submergence of the strait, and, taken with the contrary evidence seen in the Desierto Encinas, that there may have been differential warping.

COASTAL PLAIN OF THE GULF OF CALIFORNIA

South of lat. 28° N., the mountains and desert plains of the Sonoran desert give place to an alluvial plain between the mountains of the province of parallel ranges and valleys and the Gulf of California (Pl. 2). It has been formed by the coalescing of the deltas of the Ríos Yaqui and Mayo and, farther south, of the Río Fuerte. Northwest of the Yaqui toward Guaymas it is narrow, as the Sierra de Bacatete extends close to the coast. The plain is also narrow between the Ríos Mayo and Fuerte. These delta plains have, in the last two decades, been extensively reclaimed by irrigation.

The coast of the Gulf of California in this section presents many features of a shore line of emergence, with the characteristic offshore bars separated from the mainland by tidal flats and lagoons. Differential warping is suggested, however, by such harbors as Guaymas and Topolobampo which have the features of a drowned coast line.

STRATIGRAPHY

GENERAL FEATURES

The rocks in the area studied range from Paleozoic to Tertiary and Quaternary. The Paleozoic rocks crop out in small areas, but the Mesozoic rocks are extensively exposed, and those of Tertiary age are the most widespread (Pl. 1). The Paleozoic and early Mesozoic rocks are limestones, shales, and quartzites. During late Mesozoic time volcanic rocks became important and in the early Tertiary they are dominant. Although the late Tertiary rocks contain lava flows they are mostly continental conglomerates and sandstones. Most of the extensive plutonic rocks are of middle Tertiary age.

The rocks have been strongly folded and faulted, and the older ones are locally metamorphosed. There are many unconformities, correlating with times of mountain making. Fossils are not abundant, partly because of metamorphism and partly because of adverse environments. Marine invertebrate fossils are uncommon in the Paleozoic and early Mesozoic rocks but abundant in parts of the late Mesozoic. Fossil plants have been found in the early Mesozoic rocks, and vertebrate bones in the late Tertiary conglomerates.

Table 1 classifies the rocks, and lists the assigned formation names.

PALEOZOIC ROCKS

Systems represented.—Ordovician and Permian fossils occur in the area studied. The existence of Cambrian, Silurian, Devonian, and earlier Carboniferous strata in southern Arizona and adjacent parts of northern Sonora suggests that these may eventually be discovered within the region studied, but no fossils of these periods have so far been found.

Ordovician strata are definitely known in only two districts—near La Casita (Co-ord C-II) and in the Sierra de Cobachi (Co-ord B-II). At both localities a massive limestone about 160 feet thick contains a Richmond coral fauna. It is associated with dark-gray to black limestone with chert layers and concretions, siliceous shale, and thin quartzite and argillaceous buff limestone. Fossils were not found in these beds, but they may be of Lower Ordovician age.

Permian strata are more extensive and consist of great reefs of white and blue-gray massive limestones which grade laterally into thin-bedded

TABLE 1.—*Generalized stratigraphy for northern Sierra Madre Occidental within area studied*

System	Formation	Character and thickness
Tertiary	Late Tertiary *Báucarit* formation	Upper part: Coarse conglomerate and sandstone derived largely from igneous source rocks. Lower part: Conglomerate interbedded with basalt flows and basalt agglomerate.
	Folding and intrusion of batholiths	
	Early Tertiary volcanic rocks	Lava flows, tuff, and agglomerate, thinning from at least 6600 feet east of 109th meridian westward to 265 feet of chiefly rhyolitic lava, tuff, and conglomerate.
Folding		
Cretaceous		East of 109th meridian: Small areas of metamorphosed limestone and shale. On east side of valley of Sahuaripa: *Potrero formation:* Fossiliferous shale, marl, sandy brown limestone, agglomerate, and andesite flows, thickness at least 5200 feet; age upper Albian. *Palmar formation:* At top 1250 feet of alternating shale, thin-bedded quartzite, and limestone, below 2300 feet of massive bluish limestone, then thin-bedded shale, sandstone, and dense limestone with *Phylloceras*, at base about 1000 feet of massive conglomerate; age lower Albian. Between valley of Sahuaripa and 110th meridian: Limestone thins out, clastic rocks, agglomerates, andesitic lava flows thicken. West of 110th meridian: Wholly volcanic. North-central Sonora: Limestone and shale with Neocomian fossils.
Lower Jurassic and Upper Triassic	*Barranca* formation	East of 110th meridian: Fresh-water clastic rocks over 3300 feet thick, with coal, graphite, and plant-bearing carbonaceous shale near middle. Between 110th and 111th meridians: Sandstone, graphite, slate, and clay with leaf impressions and molluscan fossils, having calcareous layers in upper part; mainly of fresh-water origin but with some layers of brackish-water and marine origin; thickness about 4250 feet. West of 111th meridian: Sandstone with fossiliferous marine shale and limestone layers; total thickness at least 6300 feet.
Folding (?)		
Permian		Massive reef limestone grading laterally into thin-bedded dark, granular limestone, with abundant crinoidal fragments and fusulinids. On Cerro Cobachi 1600 feet thick.

TABLE 1.—*Generalized stratigraphy for northern Sierra Madre Occidental within area studied*—Continued

System	Formation	Character and thickness
Folding (?)		
Pennsylvanian?		Possibly present among unfossiliferous strata of the Paleozoic areas.
Mississippian?		
Devonian?		
Silurian?		
Ordovician		Coralline limestone of Richmond age; thickness 160 feet. Dark gray to black cherty limestone, argillaceous limestone, siliceous shale, and quartzite; fossils not found, but possibly Lower Ordovician.
Cambrian?		Possibly present but not recognized.

dark-gray granular limestone composed largely of shell fragments, crinoidal fragments, and fusulinids. The reef limestones form such high mountains as Cerro Cobachi (Co-ord B-II) and Cerro San Francisco (Co-ord A-II). The reef limestone of Cerro Cobachi is about 1600 feet thick.

Distribution.—Sedimentary rocks definitely of Paleozoic age are not known in the Sierra Madre Occidental province. In the few places where they are believed to be present east and southeast of the Río Yaqui in the province of parallel ranges and valleys their identification is generally uncertain.

The most extensive Paleozoic area is that first noted by Dumble (1900a, p. 148-150) northeast of La Casita. It is at least 13 miles long north and south and 7 miles wide, with the full extent of the exposures undetermined. Second in size is the Paleozoic area of the Sierra de Cobachi, 10 miles farther west. In both areas, heavy brush which covers the exposures and high and irregular dips of most of the strata are serious obstacles to the working out of the stratigraphy. The writer succeeded in determining only some of the general relations. Other areas in which Paleozoic strata occur are smaller and even less satisfactory for stratigraphic studies.

In the northern part of the Sierra de la Colorada (Co-ord A-I&II), and extending westward to the region of Hermosillo, are many exposures

of limestone and associated rocks. Crinoid stems were collected from them near Willard (Co-ord A-II) by Flores. The collections were studied by Burckhardt and assigned to the Jurassic (Flores, 1929, p. 30, 106). The writer has, however, collected fusulinids from crinoidal limestones near Zubaite and elsewhere, and from their close similarity throughout the district he is inclined to regard them all as of Paleozoic, and probably Permian, age. Age assignments on the basis of crinoid stems alone are regarded as questionable.

East of the Río Yaqui in the central mountain area of the province of parallel ranges and valleys, a few exposures of bluish-gray limestone and associated rocks resemble those of Paleozoic age farther west. No fossils have been found in them, they are strongly folded, and in places intruded by granite. However, abundant Permian fusulinids, associated with crinoidal fragments, occur in rounded cobbles of bluish limestone in conglomerates at the base of the Cretaceous Palmar limestone, near Cerro el Palmar (Co-ord D-II). Some of the unfossiliferous limestones east of the Río Yaqui may have been the source of the cobbles, the fossils being better protected from regional metamorphism in the conglomerates than they would have been in their parent ledges.

In southeastern Sonora (Co-ord D-IV, D&E-V) small exposures of limestone and quartzite may be of Paleozoic age. The only fossils reported, however, are a *Spirifer* collected by Angermann (1904, p. 88) and some crinoid stems seen by the writer. The rocks are strongly folded and faulted and considerably metamorphosed, probably by the granites which intrude them at numerous places. Near the Río Cedros and to the west of it there are local small outcrops of sedimentary rock, in places associated with andesite, which form inclusions in granite. Their age and structural relations are uncertain, but if the sedimentary rocks near the Mayo and Cedros valleys are Paleozoic these may also be.

West and north of the area studied are many scattered occurrences of altered limestone and other sedimentary rocks. They are reported north and east of Hermosillo in the region of Ures and along the route of the Ferrocarril Sud-Pacífico (Flores, 1929, p. 30-33, 154-155) and between Hermosillo and the coast in the Sierra de Tonuco (McGee, 1897, p. 91). Many of these rocks probably belong to the Permian or other Paleozoic systems, but, as noted farther on, some contain Mesozoic fossils. Further study of this area is desirable to separate the Paleozoic and Mesozoic rocks.

Table 2 summarizes the information obtained on the Paleozoic rocks, together with a résumé of other reported Paleozoic occurrences in Sonora.

Paleogeographic relations.—In southwestern New Mexico and southeastern Arizona all the Paleozoic systems have been identified (Darton, 1925, p. 38-104; Stoyanow, 1936a). Imlay's (1939, p. 1729-1733) work has shown that a thick succession of Mississippian and Permian strata occurs in northeastern Sonora. Schuchert (1923, p. 192, fig. 3) has indicated that a Paleozoic seaway extended from southeastern Arizona southward across Sonora to the Pacific Ocean. Present evidence suggests that most of Sonora east of Long. 111° W. was submerged during Carboniferous time but that pre-Carboniferous seas were more restricted.

BARRANCA FORMATION (UPPER TRIASSIC AND LOWER JURASSIC)

General features.—In the area studied, lower Mesozoic clastic rocks, largely of fresh- or brackish-water origin, contain beds of coal and graphite and fossils of Upper Triassic and Liassic age. It was named by Dumble (1900a, p. 139) for excellent exposures in the vicinity of La Barranca, east of San Javier (Co-ord C-II).

The Barranca formation crops out north of 28° N. lat. in many parts of the province of parallel ranges and valleys and in the eastern Sonoran desert province. In the ranges bordering the Río Yaqui it is almost wholly non-marine, and consists of gray, buff-weathering massive and generally quartzitic sandstone separated into two parts by a member of plant-bearing carbonaceous shale and thin-bedded sandstone. The thickness is over 3300 feet. To the west, between 110° and 111° W. long., the formation is of fresh- and brackish-water origin and consists of indurated sandstone, graphitic quartzite, impure graphite, slate, and clay with leaf impressions and brackish-water pelecypods. In the upper part are thin calcareous layers with marine pelecypods. The thickness here is about 4250 feet. In northwestern Sonora, west of the 111th meridian, it consists of sandstone and quartzite with thick fossiliferous marine shale and limestone layers, having a total thickness of at least 6300 feet.

Occurrences of the Barranca formation to the southeast of the type area are smaller and their correct assignment somewhat doubtful. Extensive exposures of the formation reported by Dumble (1900a, p. 140) from near Baroyeca (Co-ord D-IV) seem to apply to the cliffs of Cerro Colorado (Co-ord C-IV), which are actually composed of altered and silicified andesite of early Tertiary age. There are, however, small inclusions of quartzite and limestone of uncertain age in granite three quarters of a mile south of Baroyeca. The Barranca formation is doubtfully recognized farther south at the Mina Piedras Verdes (Co-ord D-V). Occurrence of the Barranca among the metamorphosed sedimen-

TABLE 2.—*Paleozoic rocks of central and southeastern Sonora*

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
			PERMIAN			
19.	Casita-Arrastras area (Co-ord C-II)					
	(a) 4 km. E. of Chapal	Dark-gray limestone, which is breccia of crinoidal fragments	Poorly preserved brachiopods, including *Linoproductus;* many fusulinids; crinoidal fragments	Undetermined	Fossiliferous Permian strata form narrow belt striking WNW, S of Ordovician area; overlapped to S by Báucarit basalt	
	(b) Near Los Oninos, on Mazatán-Soyopa highway	Massive light-gray limestone	Fossils in place not seen; in float to W, and apparently derived from it, is *Parafusulina* similar to that of Cerro Cobachi	Undetermined	Forms E-dipping ridge rising 600 feet above plains to W which are underlain by lavas	
18.	Sierra de Cobachi (Co-ord B-II)	Lenticular, reef-like limestone forms Cerro Cobachi; grades westward to thinner-bedded limestone	Thinner-bedded limestone contains two species of fusulinids, including a *Parafusulina* resembling a species from Leonard formation of trans-Pecos Texas; crinoid stems	On Cerro Cobachi about 1600 feet	*See* Figure 2-B	Assigned by Dumble (1900a, p. 134) to Cretaceous on basis of indefinite hippuritid and sponge forms in chert; great open cave on S face Cerro Cobachi formed from solution of limestone
17.	Northern end of Sierra de la Colorada (Co-ord A-I & II)					
	(a) Cerro San Francisco	Massive light-gray limestone, probably a reef, forms Cerro San Francisco; grades westward into thin-bedded cherty limestone; E of peak more siliceous lower beds occur; S of peak dark-gray cherty limestones with Permian fossils but of uncertain relations to rest of section, overlain to S by fine-grained shattered quartzite	Thin-bedded limestone W of Cerro San Francisco contains fusulinids; limestone S of peak contains abundant crinoid stems and fusulinids	Over 500 feet	*See* Figure 2-C. Limestones S of peak dip S and overlying quartzites occurring ½ mile N of Zubiate, are overlain by lava in Zubiate valley	
	(b) Cerro Zubiate	Massive light-gray limestone forms Cerro Zubiate; to SE are shattered red-weathering quartzites	None found	About 500 feet	Limestone dips SW, intruded by granite dikes; quartzites overlain to SE by lavas	Assigned to Permian by King on lithologic resemblance to Permian of Cerro San Francisco
	(c) Cerro Sonora	Massive limestone	Crinoid stems (Flores, 1929, p. 106)	Undetermined		Not visited by King

(d) Cerro Tordillo and Cerro Calera	Massive limestone	None reported	Undetermined		Not visited by King
16. Sierra de Santa Teresa (Co-ord A-II)	Limestone	None reported	Undetermined		Mapped by Flores; tentatively assigned to Permian by King on lithology
15. E of Willard (Co-ord A-II)	Limestone, part crinoidal	NE of Willard, crinoidal fragments with some fusulinids; E of Willard crinoid stems collected by Flores	Undetermined	Forms low range of hills	Crinoid fragments believed by Flores to indicate Jurassic age
14. Cerro de la Flojera (Co-ord A-I & II)	Granular crinoidal massive limestone alternates with dense, thin-bedded, unfossiliferous limestone	Crinoidal fragments abundant; King noted fusulinids in field, but none found in collections studied by Dunbar	Undetermined	Forms low SW-dipping cuesta	
13. Hills in and S of Hermosillo (Co-ord A-I & II)					
(a) Sierra de Doña Marta	Crystalline, metamorphosed limestone	None found	Undetermined	Limestone in small areas in range striking E-W along S side Río de Sonora; attitude vertical, cut by granite dikes	Assigned to Permian by King on lithology
(b) Cerro de la Campana (in SE part city of Hermosillo)	Highly altered siliceous limestone	None found	Undetermined	Isolated hill	Assigned to Permian by King on lithologic resemblance to limestone of 17a. Placed in Cretaceous (Anonymous, 1924, p. 373) and in Jurassic by Flores (1929, p. 30); evidence for these assignments not given
(c) Hills between Villa de Seris and Represo Dewey	Limestone	None found	Undetermined	Detached limestone areas rising from granite pediment	Assigned to Permian by King on lithology
12. Vicinity of El Trigo, Cedros valley (Co-ord D-IV)	On Arroyo del Templo N of El Trigo, quartzites interbedded with lesser amount of brown and black hard limestone, part of which is thin-bedded, with bituminous laminae; near El Trigo limestone; at Mina del Trigo quartzite with some careous layers	Angermann (1904, p. 88) found poorly preserved brachiopod, apparently a *Spirifer*, in limestone near El Trigo	Undetermined	Exposures occur for 1½ miles along Arroyo del Templo, where quartzites are intensely shattered and limestone layers crumpled, altered, and cut by calcite veins; between Arroyo del Templo and exposures at and S of El Trigo is granitic intrusive. *See* Figure 2-D	*Spirifer* suggests late Paleozoic age; assignment to Permian doubtful

TABLE 2.—*Paleozoic rocks of central and southeastern Sonora*—Continued

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
11.	Between Mátape and Batuco (N of area studied by King, located NE of Mazatán)	Limestone	"Fine fossils" reported E of Topisco. At Cerro de la Bonacina "a variety of corals, crinoids, and brachiopods . . . weathered out from the surface of several beds of hard, compact limestone"	"A great thickness" E of Topisco	Limestone flanks N-S range of granite; has synclinal structure; strata much disturbed	Described by Rémond (1866, p. 249); fossils reported suggest Permian
			ORDOVICIAN			
10.	NE of La Casita (Co-ord C-II)	(a) Massive blue-gray limestone, weathering white, with pitted surface; has stringers of black chert	Corals, including abundant *Palaeophyllum*, rare *Calapoecia*, *Streptelasma*, and *Heliolites;* age Richmondian	About 160 feet	Forms low ridges in southwestern part of Casita-Arrastras Paleozoic area. *See* Figure 2-A	
		(b) Dark-gray to black limestone with brown and black chert layers and concretions, siliceous shale, thin-bedded quartzite, and argillaceous buff limestone; in places contains angular chert-pebble conglomerate and at one locality platy dark limestone brecciated into broad, flat pebbles	Not found	Undetermined	Occurs adjoining limestone of (a) to N and E, and appears to underlie it; dip variable, strike generally E-W	Lithology resembles that of Lower Ordovician Marathon formation of trans-Pecos Texas; these beds probably the ones assigned by Dumble to Cambrian
9.	Cerro Goyete, in Sierra de Cobachi (Co-ord B-II)	Massive white limestone	Coral fauna similar to that at 10a	Over 100 feet	Dips SE, relation to beds on NE and SW uncertain	
			UNDIFFERENTIATED PALEOZOIC			
8.	Casita-Arrastras area (Co-ord C-II)	White limestone, shale, and chert conglomerate	Not found	Undetermined	Limestone forms hills between Ordovician area of 10a and Permian area of 19b; shale and conglomerate occur in intervening valleys	

7. Sierra de San Javier (Co-ord C-II)					
(a) Los Bronces valley 1¾ miles NNE of San Javier	Gray limestone with stringers of chert	Not found	Undetermined	Dips 80° S in small area surrounded by shattered quartzite	Lithologically resembles older Paleozoic of Casita area, but may be Triassic
(b) Between Los Bronces and Soyopa	Not stated	Unreported	"A considerable exposure"	Beds stand nearly on edge, strike NE	Reported by Dumble (1900a, p. 150) as Cambrian
6. Sierra de Cobachi (Co-ord B-II)					
(a) SW of Cerro Cobachi	Shale, sandstone, limestone	Not found	Undetermined	Dips and strikes very irregular; in places so highly jointed that stratification not evident. *See* Figure 2-B	Lithology suggests correlation with Lower Ordovician (?) of Casita area
(b) 3 km. N of Cerro Goyete	Limestone	Crinoid columns and bryozoa	Undetermined	Occurs in small area on Cobachi-El Pozo road	
(c) S of Cerro Goyete	Red quartzitic sandstone and cherty limestone	Not found	Undetermined	Structure complex	
(d) N side of Cerro Cobachi	Banded quartzites and marbles	Not reported	Undetermined	Stand at high angle, overlain to SE by Ordovician; low - dipping Permian limestone of Cerro Cobachi rests unconformably on steeply-dipping pre-Permian	Reported by Dumble (1900a, p. 135, 149, and 151). Not seen by King
5. East of Tónichi (Co-ord C & D-II)					
(a) Edge of mountains at Agua Caliente, 4 miles NE of Tónichi	Thin-bedded limestone with bands of chert	Crinoid columns	Undetermined	Dip 70° NW, intruded by pegmatitic granite on E	Lithologically resembles older Paleozoic of Casita area
(b) Guamóchil	Black and bluish limestone interbedded with black chert, slate, and some quartzite, overlain by coarse-grained gray limestone, silicified on surface	Not found	Undetermined	Lower strata strongly folded and faulted, occur ¼ mile N and ½ mile SE of Guamochil; upper limestones occur W of Guamóchil, overlain by or faulted against Barranca quartzite. *See* Figure 3-C	Lower strata resemble older Paleozoic of Casita area; overlying limestone may be Permian
4. Río Chico de Ostimuri (Co-ord C-II)	Limestone and quartzite	Not found	Undetermined	Small exposure in hill N of village, intruded and surrounded by granite	
3. Headwaters of Arroyo Arenoso (Co-ord D & E-V)	Gray-brown quartzitic sandstone overlain by hard, granular unfossiliferous limestone	Fossils not found in place, but in lower course of arroyo limestone boulders up to 1 meter in diameter have abundant cross-sections of crinoid stems and other unidentifiable fossils	Undetermined	Two ridges rise about 800 feet above granite plain to SE; structure probably synclinal. *See* Figure 2-E	

TABLE 2.—*Paleozoic rocks of central and southeastern Sonora*—Continued

No. Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
2. Lower valley of Río Cedros (Co-ord D-V)					
(a) 5 miles S La Casita and 1 mile W of Río Cedros	Limestone, red and white quartzite, and slate	Limestone contains crinoid stems, corals, and brachiopods	Undetermined	Limestone and quartzite vertical, striking N-S, forming hill 1000 feet high, intruded by quartz monzonite; slates lie to N, andesite to S and W	Reported by Angermann (1904, p. 86)
(b) Between Agua Caliente and Sobia on E bank Río Cedros	Black shale, granular limestone, and quartzite	Not reported	Undetermined	Underlies Báucarit conglomerate	Reported by Dumble (1900a, p. 150; regarded by him as Cambrian. Not found by King
1. Localities W of Cedros valley					
(a) Mina de la Escondida, S of Cedros (Co-ord D-IV)	Quartzite, altered by contact metamorphism	Not found	Undetermined	Quartzite and andesite form scattered hills in granite pediment	
(b) Nabamora (Co-ord D-V)	White to bluish limestone, quartzite, and micaceous phyllite	Not found	Undetermined	Forms narrow strip intruded by granite	
(c) Cabora (Co-ord C-V)	Limestone				Reported locally, not seen by King
(d) SW of Batacosa (Co-ord D-V)	Coarsely crystalline altered limestone; quartzite	Not found	Undetermined	Occur in two small inclusions in granite, about 100 feet across	
(e) ½ mile S Baroyeca (Co-ord D-IV)	Quartzite and limestone	Not found	Undetermined	Inclusions in granite	At La Calera, 3 miles NW Baroyeca, limestone is reported locally, not seen by King
(f) Mina Báucarit (Co-ord D-V)	Limestone (?)			Calcite veins in igneous rock suggest presence of limestones in vicinity	

tary rocks in the Sierra Madre Occidental province is based on local occurrence there of coal and graphite.

Overlying the Barranca formation is a thick sequence mainly of volcanic origin, which Dumble believed to be a part of the Triassic succession and named the Lista Blanca formation. Present evidence suggests that these rocks are of Cretaceous age. Flores assigned many of the

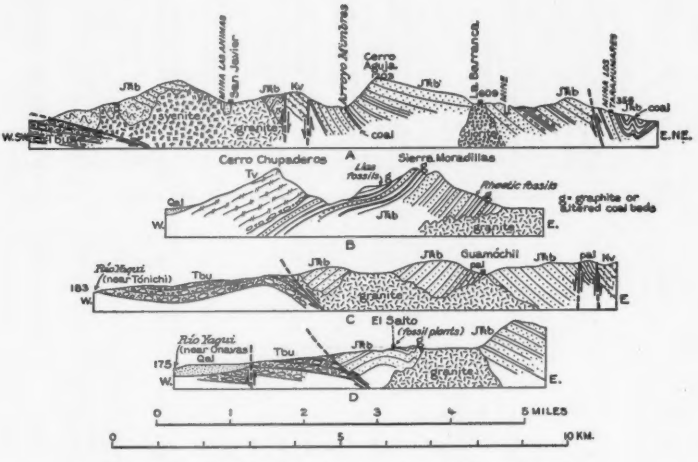


FIGURE 3.—*Sections showing structure and stratigraphy*

Outcrops of Barranca formation in central Sonora.
(A) Southern Sierra de San Javier, the type area (Co-ord C-II). (B) Sierra de Mouradillas (Co-ord B-II) (modified from Flores). (C) Vicinity of Guamóchil (Co-ord D-II). (D) East of Ónavas (Co-ord D-III). (pal) Paleozoic rocks; (JTrb) Barranca formation; (Kv) and (Tv) volcanic rocks of Cretaceous and Tertiary age; (Tbu) upper member of Báucarit formation; (Qal) alluvium. Heights in meters.

sedimentary rocks of the Hermosillo-Ures region to the Upper Jurassic, on the basis of crinoid stems. As noted, however, these rocks in places contain Permian fusulinids.

Table 3 gives data on the Barranca formation obtained both from observations and from the literature.

Fossils.—The eastern nonmarine facies of the Barranca formation contains a rich fossil flora. The best known localities are in the coal-bearing member of the formation in the southern Sierra de San Javier (Co-ord C-II). Collections from this area have been made by Rémond, Dumble, and others, and have been studied by Newberry (1876), Humphreys (1916), and Wieland (1926). The following species are listed by the

TABLE 3.—*Barranca formation of Sonora and Chihuahua*

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
16.	Sierra de San Javier (Co-ord C-11)					
	(a) General characteristics	Gray, buff-weathering, massive, and generally quartzitic sandstone, separated into two parts by a medial member of shale and thin-bedded sandstone; middle member contains seams of coal and graphite. (*See* Plate 5, section 8.)	*See* text	Over 3,300 feet	Barranca formation comprises almost all of this range, except small areas of probably Cretaceous andesite; extent north of 29th parallel undetermined; in most parts of range structure complicated by faulting, igneous intrusions, and shattering. *See* Figure 3-A	
	(b) Cerro Aguja section	Upper member: Massive gray quartzitic sandstone, weathering reddish brown Middle member: Shale and thin-bedded sandstone, containing beds of coal and coarse conglomerate Lower member: Alternating sandstone, conglomerate, and dark shale; base not exposed	Not collected from this locality	Upper member at least 1,600 feet Thickness middle and lower members undetermined	Upper member caps Cerro Aguja and other peaks on same strike, dipping 20° SE Middle member exposed in valley of Arroyo Mimbres along W side Cerro Aguja, dipping 45-55° SE Lower member exposed W of Mimbres valley toward Los Bronces, dipping irregularly	
	(c) Santa Clara coal field, in Arroyo de los Tarahumares	Coal occurs probably in middle member; each prominent bed of slate and shale seems to have one or more seams of coal in it. In upper part of middle member in this vicinity Dumble reports thin lenticular beds of argillaceous limestone	*See* text		Coal is anthracite, containing 76 to 85% fixed carbon; near igneous intrusions altered to a natural coke	Deposits more or less lenticular but nearly all beds workable somewhere along their extent; formerly mined and used at silver mines of San Javier; description from Dumble (1900b)
	(d) Hill N of Lodecampa	Argillaceous and carbonaceous strata of middle member overlain by massive quartzite	Not reported from this locality	Total not measured	On southern escarpment of Sierra, cut off to S probably by a fault	Described by Dumble (1900a, p. 141)
	(e) Los Bronces valley	Middle member of formation well exposed, containing coal seams 7 to 10 feet thick, according to Dumble	This is given as locality for flora collected by Rémond and described by Newberry	Not measured		
	(f) Halfway between La Guásima and Llano Colorado on Mazatán-Soyopa highway	Ash-gray to black limestone and siliceous, argillaceous, calcareous rock, seemingly interbedded with typical Barranca quartzite	Not found	Undetermined	In area of complex structure	May be Paleozoic but appear to lie in Barranca

15. Toledo (Co-ord C-II)	Quartzitic sandstone	Not found	Undetermined	Isolated area in middle of Yaqui valley, surrounded by Báucarit conglomerate	
14. Ranges E and NE of Ónavas (Co-ord C & D-II & III)					
(a) 2½ to 4 miles E of Ónavas (Co-ord D-III)	Massive sandstones containing argillaceous horizon and several layers of graphite up to 3 feet thick near igneous contact	Argillaceous beds at a spring E of anticlinal axis contain numerous cycad leaves	Exposed thickness about 1,300 feet	3 miles ENE of Ónavas is axis gentle anticline, intruded to N by granite; Barranca beds thrust to W upon Báucarit conglomerate. *See* Figure 3-D	
(b) Vicinity of El Carrizal (Co-ord D-II)	Quartzite containing coal seams	Not found	Undetermined	Small exposure intruded by granite on W, overlain by andesite on E	
(c) Los Pilares-El Pinito area (Co-ord D-II)	At Los Pilares quartzite contains seams of slaty coal up to 3 feet thick; at El Pinito massive sandstones contain graphite bed	At Los Pilares laminated carbonaceous sandstone overlying coal contains plant leaves; see text	Undetermined	Barranca formation is intruded by granite to NW and W, overlain unconformably to E by andesite, to S by Báucarit conglomerate	
(d) Vicinity of Cervantes (Co-ord D-II)	E of Cervantes thick massive quartzites; in Arroyo Tibursari below Cervantes reddish banded quartzite and hard shale with carbonaceous bands	Not found	Undetermined	Quartzites E of Cervantes overlain by andesite	
(e) Guamóchil, El Rodeo, and Tibursari (Co-ord D-II)	Red-brown quartzites with carbonaceous seams	Not found	Undetermined	Overlies or is downfaulted against Paleozoic (?) limestone. *See* Figure 3-C	
(f) Vicinity of San Marcos (Co-ord D-II)	Reddish quartzite with carbonaceous seams	Not found	Undetermined		
13. Ranges S and E of La Dura (Co-ord C & D-III)					
(a) NE and E of La Dura (Co-ord C-III)	Red quartzite	Not found	Undetermined	Quartzite is intruded and altered by granite, forming rounded hills	
(b) La Gloria mine (Co-ord C-III)	Black dense quartzite	Not found	Undetermined	Exposed on both banks of Río Yaqui	
(c) Vicinity of Río Chico de Ostimuri (Co-ord C & D-III)	Red quartzite	Not found	Undetermined	Disconnected reddish ridges and mountains altered by granitic intrusions	
12. Vicinity of Mina Piedras Verdes (Co-ord D-V)	Red quartzite and sericite schist	Not found	500 feet	Forms E-W range of hills, intruded to N and S by granite, so much jointed that bedding is indistinguishable	Noted by Angermann (1904, p. 86), Dumble (1900a, p. 151), and Botsford (1911, p. 704). Considered by Dumble to be Archean for reasons not stated

TABLE 3.—*Barranca formation of Sonora and Chihuahua*—Continued

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
11.	Possible occurrences in Sierra Madre					
	(a) Sahuayacán area (Co-ord E-III)	Graphitic slate interbedded with quartzite	Not found	Undetermined	Occurs in area of metamorphosed sediments	Presence of graphite suggests correlation with Barranca
	(b) Siriáchic, on N side Río Mayo E of La Trompa (Co-ord E-IV)	Graphite and coal			Not seen by King	Reported locally
	(c) Guayjura, on Río de Oteros (Probably Co-ord F-IV)	Graphite			Not seen by King	Reported locally
	(d) N and NE of Moris (Co-ord E & F-III)	Quartzite associated with limestone	Not found	Undetermined	Occur along fault scarp, structure very complex, somewhat altered. *See* Figure 5-B	Possibly includes both Barranca and Cretaceous strata
10.	Between San Javier and Suaqui Grande (Co-ord C-II & III)	Quartzite	Not found	Undetermined	Occurs west of Limón and in Cerro Suaqui range	
9.	Sierra de Tecoripa (Co-ord B & C-II)	Quartzite (?) with graphite reported beneath massive upper member SW of Tecoripa	Not found	Undetermined, but apparently great thickness present	Forms high E-W range, intruded by granite on N	King did not enter this range
8.	Sierra de Cobachi (Co-ord B-II)	Quartzite	Not found	Undetermined	Forms central and southern parts of range, intruded by granite	
7.	Cerro Avispa (Co-ord B-II)	Quartzite	Not found	Undetermined	Anticlinal uplift with lava on flanks	
6.	Sierra de Moradillas and Cerro Colorado (Co-ord B-II)	Highly graphitic quartzites and indurated sandstones, thick beds impure graphite, at El Salto a thin bed of coal, clays with fossil plants and pelecypods; formation more calcareous near top. *See* Plate 5, section 7	Leaf impressions and *Panope rémondi;* shale with Lias pelecypods at Mina la República (*See* text)	4,250 feet	Intruded by granite and overlain by pyroxenic andesite. *See* Figure 3-B	Not visited by King; description from Flores (1929, p. 107) and Dumble (1900a, p. 141). *See also* Santillán (1936, p. 397-398)
5.	Possible occurrences in Sierra de la Colorada (Co-ord A-II)	Quartzites and other altered sedimentary rocks	Not found	Undetermined		Some of these are probably Barranca but included in areas of principally Paleozoic rocks

4. Sierra de Santa Rosa, 30 miles W of Puerto (Fig. 1), near Mina Santa Rosa and Cajón de las Amarillas	3) Shaly sandstone, shale, and shaly limestone. 2,600 feet 2) Alternating argillaceous limestone and sandstone. 3,300 feet 1) Red micaceous sandstone and gray massive quartzite. 1,300 feet. *See* Plate 5, section 6.	Liassic fauna from horizon No. 3; lower portions of section possibly Upper Triassic	7,200 feet	Occur in anticline; base of section not exposed; sedimentary rocks capped by rhyolite	Described by Keller (1928, p. 332)
3. Las Ánimas, 12 miles W of Puerto (Fig. 1)	Yellow-brown limestone overlying shales	*See* text	Undetermined	Occurs in small hill rising from plain	Reported by Flores (1929, p. 150-151) and Burckhardt (1930, p. 24)
2. Sierra de Caracahui, 5 miles ENE of Puerto (Fig. 1)	Limestone, shale, and sandstone	*See* text	Undetermined	Sedimentary rocks form S end of range	Reported by Flores and Burckhardt
1. Mina el Antimonio, 30 miles W of Caborca (Fig. 1)	8) Gray sandstone, upper part conglomeratic. 800 feet 7) White quartzite interbedded with shale. 650 feet 6) Light-gray sandstone, shale, and sandy limestone. 650 feet 5) Massive limestone. 30 feet 4) Brown shale and argillaceous limestone. 1,000 feet 3) Red shale and sandstone with thin beds limestone. 100 feet 2) Red shale and red calcareous sandstone. 200 feet 1) Red and brown sandstone, some sandy shale, gray limestone, and quarts pebble conglomerate. 300 feet *See* Plate 5, section 5	Beds 8 to 6 unfossiliferous, may be Rhaetic Beds 5 and 4 have Noric pelecypod; 5 has abundant broken shells Bed 3 has rich Karnic fauna	3,730 feet		Described by Keller (1928) and Baker (in section quoted by Burckhardt 1930, p. 6); first mention of this locality by Burckhardt (1923)

three paleobotanists, the specific name being followed by the initials of the author of the citation:

Otozamites macombii Newberry (NH)
Pterophyllum fragile Newberry (N)
P. robustum Newberry (N)
Podozamites crassifolia Newberry (N)
Zamites powellii Fontaine (H)
Palissya sp. (H)
Pecopteria (Mertensides) bullatus Bunbury (NH)
P. falcatus Emmons (NH)
P. mexicanus Newberry (N)
Alethopteris whitneyi Newberry (N)
Camptopteris rémondi Newberry (N)
Taeniopteris elegans Newberry (N)
T. magnifolia Rogers (N)
T. glossopteroides Newberry (N)
Macrotaeniopteris sp. (H)
Jeanpaulia radiata (Newberry) (N)
Neocalamites carrerei (Zeiller) Halle (H)
Asterocarpus virginiensis Fontaine (H)
Lacopteris münsteri Schenk (W)

Fossil plants collected by the writer east of Ónavas (Co-ord D-III) and at Los Pilares (Co-ord D-II) have been examined by Mr. Charles B. Read of the United States Geological Survey. Those collected near a spring 2½ miles east-northeast of Ónavas include *Pterophyllum fragile* Newberry and *Pecopteris bullatus* Bunbury. Collections made at two localities near Los Pilares each contain *Taeniopteris magnifolia* Rogers and *Lacopteris* ? sp.

Burckhardt (1930, p. 39) gives the following résumé of ideas regarding the flora:

"On the basis of the plants studied by him, Newberry placed the beds of Sonora in the Rhaetic, mentioning resemblances with the Triassic floras of Abiqui, New Mexico, Richmond, Virginia, and North Carolina, and with the Rhaetic of Bayreuth and other European localities. Wieland agrees with Newberry . . . and thinks that the beds are Triassic . . . and that the abundance of *Taeniopteris* and *Pterophyllum* . . . and the presence of species unlike those observed in Oaxaca indicates that they are older than the plant bearing strata in southern Mexico."[2]

According to Read, the flora is

"unquestionably Upper Triassic, carrying one species, *Taeniopteris magnifolia* Rogers, which is also known from the Newark group of Virginia. *Pecopteris bullatus* Bunbury is a rather characteristic Upper Triassic plant. *Pterophyllum fragile* Newberry has been collected from the Dockum group (Triassic) of West Texas, but is not known elsewhere."

Dumble (1900b, p. 12) reports that one of the argillaceous limestone beds of the middle member of the formation in the Santa Clara coal field near San Javier (Co-ord C-II) contains imprints of many unidentifiable marine invertebrates.

About 50 miles west of the plant localities in the Sierra de San Javier, in the Sierra de Moradillas (Co-ord B-II), both fossil plants and brackish-water or marine invertebrates occur in the Barranca formation. At the barranca of El Salto abundant fossil plants have been collected, as well as *Panope rémondi* Gabb[3] (Flores, 1929, p. 107), which is considered to be of Rhaetic age. In shale at the Mina la República Flores collected *Pecten* group of *P. pradoanus* Verneuil and Collomb (*Neithea*

[2] Free translation from the original French.
[3] Described from "west of San Marcial" by Gabb (1864, p. 28).

mexicana Jaworski) and *Pecten* cf. *P. textorius* Schlotheim.[4] The latter are considered to be of lower or middle Lias age by Burckhardt.

A supposed resemblance of the metamorphosed sedimentary rocks in the mountains of northwestern Sonora to the quartzites, slates, and limestones of the gold belt of the California sierras early led to their classification as lower Mesozoic (Rémond, 1866, p. 246; McGee, 1897, p. 93). Fossil evidence subsequently confirmed the presence of lower Mesozoic rocks in the complex, when Keller (1928) and Baker[5] reported Upper Triassic fossils in the region, and Liassic strata were described by Keller and by Flores (1929, p. 150-151).

At the Mina el Antimonio, 30 miles west of Caborca (Fig. 1), a 100-foot bed, 490 to 560 feet above the base of the formation, contains a rich Karnic fauna. This has been listed by J. P. Smith[6] and Keller (1928) as follows, the letter following the name of the fossil indicating the source of the citation:

Bryozoans (K)
Isocrinus californicus Clark (K)
Spiriferina sp. (S)
Halobia cf. *superba* Mojsisovics (S)
Gastropods (SK)
Orthoceratoids (SK)
Calliconites dieneri Gemmellaro (S)
Proclydonautilus triadicus Mojsisovics (S)
Cosmonautilus pacificus Smith (S)
Tropites cf. subbullatus (Hauer) (SK)
T. cf. *dilleri* Smith (S)
T. occidentalis Smith (S)
Paratropites dittmari Mojsisovics (K)
P. anakreontis Mojsisovics (S)
P. sellai Mojsisovics (K)
P. cf. *valvasoris* Mojsisovics (S)
Margarites ? sp. (K)
Discotropites lineatus Smith (S)
D. quinquepunctatus (Mojsisovics) (S)
D. gemmellaroi Smith (S)
D. sulcatus (Calcara) (S)
Tropiceltites ignatii Mojsisovics (S)
Juvavites strongi Smith (S)
Sagenites (Trachysagenites) hystrix Gemmellaro (S)
Metasibirites frechi (Hyatt and Smith) (S)
M. mojsvarensis Smith (S)
Arcestes pacificus Hyatt and Smith (SK)
Trachyceras sp. (K)
Sirenites lawsoni Hyatt and Smith (S)
S. pamphagus (Dittmar) (K)
Trachyceras (Protrachyceras) pollux Mojsisovics (S)
Sandlingites cf. *castelli* Mojsisovics (S)
Arpadites gabbi (Hyatt and Smith) (K)
Polycyclus nasturtium (Dittmar) (SK)
Drepanites sp. nov. (S)
Anolcites sp. (K)
Aulacoceras sp. (K)
Ichthyosaur remains (SK)

A shale zone 1000 feet thick directly above the Karnic horizon contains *Pseudomonotis subcircularis* Gabb, a Noric pelecypod.

A Lias fauna occurs in the upper part of a thick sedimentary succession in the Sierra de Santa Rosa, 30 miles west of Puerto (Fig. 1). Jaworski (1929) has identified the following forms from this locality:

Pentacrinus sp. indet.
Rhynchonellids
Terebratulids
Neithea mexicana Jaworski
Plagiostoma cf. *exaltata* Terquem
Lima nodulosa Terquem
Arca sp. indet.
Alectryonia gregarea Sowerby
Gryphaea sp. indet.
Trigonia cf. *inexpectata* Jaworski

[4] Listed by Burckhardt (1930, p. 24), who gives the locality as El Lápiz Viejo. Judging from the account of Flores (1929, p. 107), the actual location seems to be several miles farther south.

[5] A section by Baker is given by Burckhardt (1930, p. 6). The discovery was first announced by Burckhardt (1923).

[6] In letter to C. L. Baker, 1925.

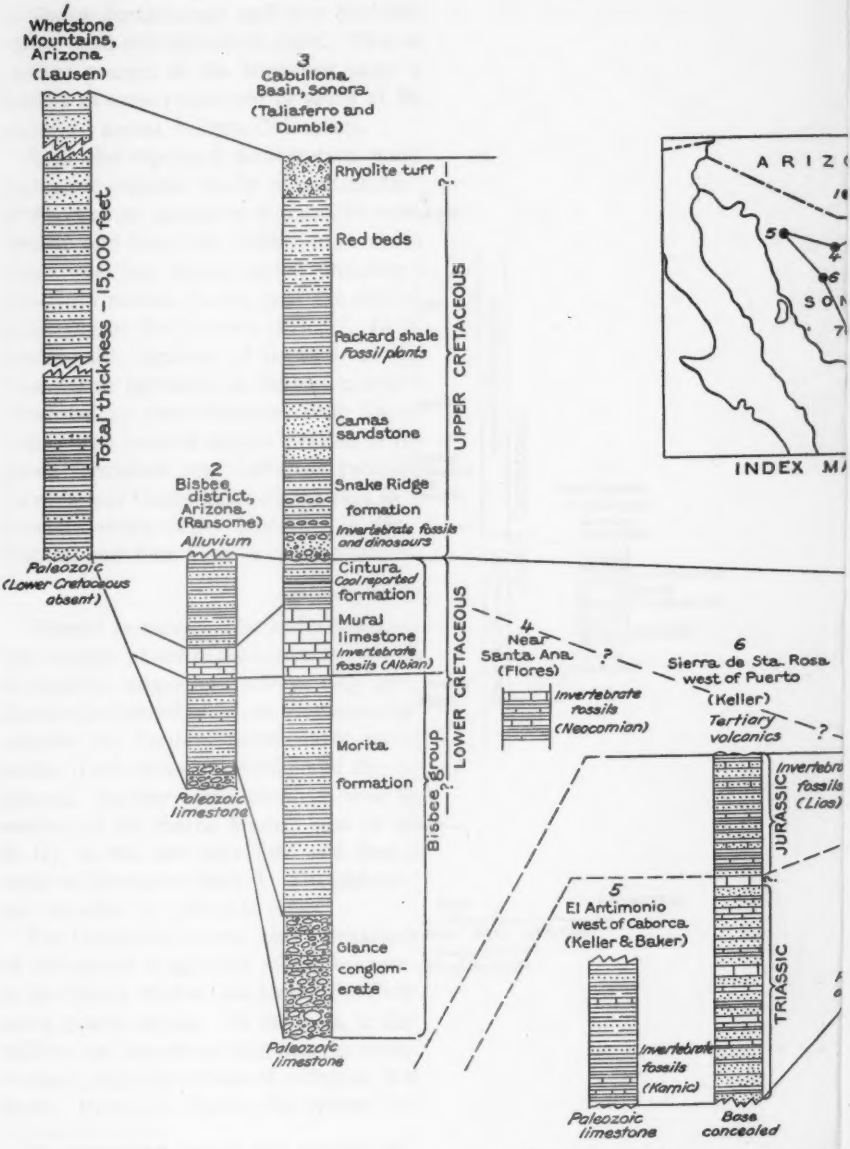
Astarte cf. *antipodum* Giebel
Myoconcha cf. *valenciennesi* Bayle and Coquand
Ammonoidea sp. indet.
Belemnites

At Las Ánimas, 12 miles west of Puerto, Flores (1929, p. 150-151) collected from a yellow-brown limestone *Pecten* (*Aequipecten*) group of *P. priscus* Schlotheim, sections of gastropods, and remains of bryozoans. In the Sierra de Caracahui, 5 miles east-northeast of Puerto, he collected from limestone and shale *Pecten* group of *P. pradoanus* Verneuil and Collomb (*Neithea mexicana* Jaworski), *P.* (*Aequipecten*) group of *P. priscus* Schlotheim, and crinoid stems. (See also Burckhardt, 1930, p. 24.)

Possible equivalents to north.—In northeastern Sonora and southeastern Arizona, no equivalents of the Barranca formation are certainly known. Dumble (1902, p. 706-707) stated that plants and invertebrates in clastic rocks on the flank of the Whetstone Mountains (Fig. 1) were very similar to those in the Barranca; he suggested for them a Triassic age. This led Schrader (1915, p. 54) to infer that part of the similar clastic rocks of the near-by Santa Rita and Patagonia Mountains were also Triassic. Little has since been published on this interesting Mesozoic section, but recent work has shown that most of it is certainly of Cretaceous age (Stoyanow, 1937; 1938).

The writer suggested (King, 1934, p. 91) that the Glance and Morita formations, at the base of the Mesozoic section in the Bisbee and Cabullona areas, are correlative with the Barranca; this interpretation was based on the clastic character of the units whose correlation was suggested, the rapid southward thickening of the Glance and Morita, and the absence at that time of fossil evidence of Cretaceous age for the Glance and Morita. As will be pointed out, recent work in southeastern Arizona, northeastern Sonora, the southwestern New Mexico has revealed convincing evidence that the Glance and Morita are clastic facies of the Cretaceous; hence the writer's previous interpretation must be abandoned.

Paleogeographic relations.—In northeastern Sonora and southeastern Arizona, the upper Paleozoic limestones are overlain directly by Lower Cretaceous clastic deposits. Farther south, in the area studied by the writer, the easternmost definite occurrence of the Barranca formation is in the province of parallel ranges and valleys. Near Sahuaripa, at the western edge of the barranca section of the Sierra Madre, the lowest exposed Cretaceous strata contain fragments of Permian limestones and may therefore rest directly on the Paleozoic. Remnants of the Barranca may occur in the central part of the Sierra Madre in western Chihuahua. In central and eastern Chihuahua, the oldest known Mesozoic rocks are



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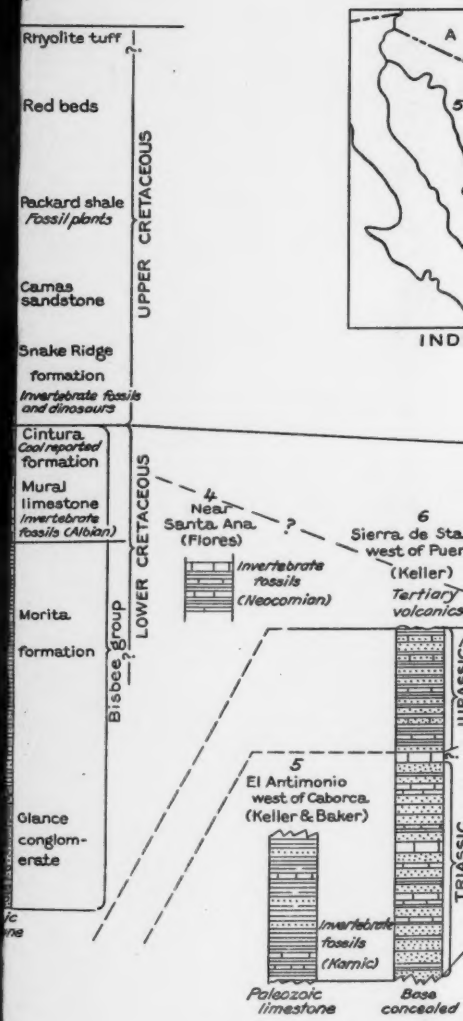

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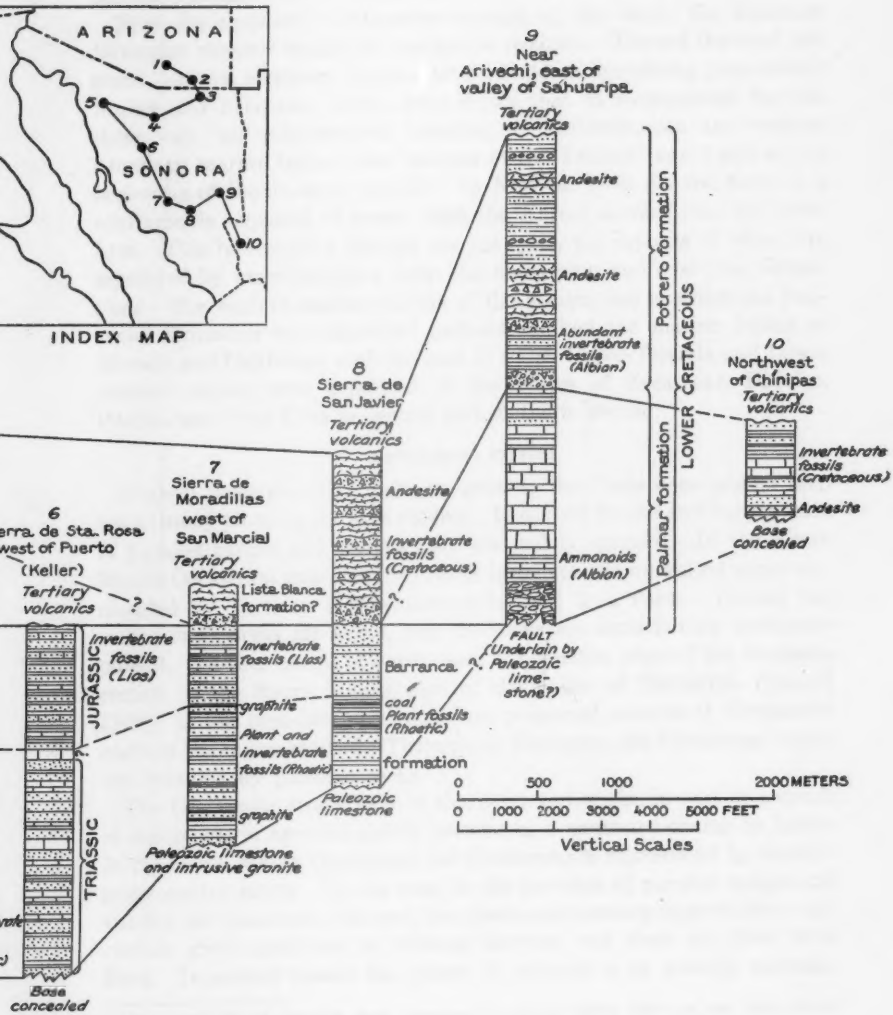


SECTIONS OF MESOZOIC ROCKS

by the writer and from various published sources.

of Upper Jurassic age, and it is doubtful if any equivalents of the Barranca were ever deposited there. This evidence suggests that the northeastern margin of the Barranca basin must have crossed northeastern Sonora at some point near or south of Nacozari, extending thence southeastward across western Chihuahua.

Near the supposed northeastern margin of the basin, the Barranca formation consists wholly of continental deposits. Toward the west and south, marine members become intercalated in increasing proportion.[7] Muller and Ferguson (1936) have shown that in west-central Nevada there was "an uninterrupted mingling of Mediterranean and western American marine faunas near the end of the Triassic period and at the beginning of the Jurassic period." In Nevada, as in Sonora, there is a conformable sequence of strata from the Karnic upward into the lower Lias. This represents a distinct marine cycle, the deposits of which are separated by unconformities from the underlying and overlying formations. The western marine portion of the geosyncline in which the Barranca formation was deposited probably linked the marine basins of Nevada and California with the seas in which Upper Triassic and Lower Jurassic strata were deposited in the States of Zacatecas, Hidalgo, Puebla, and Vera Cruz in central and southern Mexico.

CRETACEOUS SYSTEM

General features.—The rocks assigned to the Cretaceous system crop out at many places in the area studied. In central Sonora and the province of parallel ranges and valleys they are widely exposed. In the Sierra Madre Occidental province they occur in inliers and upfaulted areas surrounded by Tertiary sedimentary rocks and lava flows. Toward the south, these areas are small, and the rocks are considerably metamorphosed. Farther north, however, near the western edge of the barranca section of the Sierra Madre, east of the valley of Sahuaripa (Co-ord D-II), is the best-developed and best-preserved section of Cretaceous rocks in the region studied. Throughout the region, the Cretaceous strata are intruded by plutonic rocks.

The Cretaceous strata vary in character and origin, in part as a result of differences in age, but chiefly because of a westward change in facies. In the Sierra Madre Occidental, the Cretaceous is represented by fossiliferous marine strata. To the west, in the province of parallel ranges and valleys, the limestones thin out, the clastic sedimentary rocks thicken and contain great quantities of volcanic detritus, and there are thick lava flows. In central Sonora the system is believed to be entirely volcanic.

[7] The northwestward transition from nonmarine into partly marine beds has also been pointed out by Burckhardt (1930, p. 41-42).

For the volcanic rocks of the central portion of Sonora, here considered to be of Cretaceous age, Dumble (1900a, p. 143-144) proposed the name Lista Blanca formation, from exposures at Cerro Lista Blanca, southwest of San Marcial (Co-ord B-III). He considered the formation to be of Triassic age and to be conformable with the Barranca, but reasons for revising this interpretation are given here. The writer proposes the terms Palmar and Potrero formations for subdivisions of the fossiliferous section near Sahuaripa. Elsewhere, the Cretaceous system has not been divided into formations.

Table 4 summarizes the characteristics of different occurrences of the Cretaceous rocks of Sonora and adjacent States.

Sierra Madre Occidental province.—The outcrops of Cretaceous strata east of the valley of Sahuaripa extend northward from near El Valle de Tacupeto probably to beyond the Río Yaqui. The rocks are dominantly of sedimentary origin, are quite fossiliferous, and reach a thickness of more than 10,400 feet (Pl. 5, section 9).

For convenience in description, the section is divided into two parts. The lower division is here named the Palmar formation, from its excellent exposure on Cerro el Palmar, east of Bámori, which rises about 3400 feet above the town. A coarse, lenticular conglomerate at the base of the formation is overlain by alternating limestone, shale, and sandstone, and then by massive limestone with quartzite interbedded in the upper part. The upper division is named the Potrero formation, from the ranch El Potrero east of Cerro el Palmar. The formation consists of shale, locally fossiliferous, thin-bedded brown limestone, and contemporaneous flows of andesite.

The fossils of both formations indicate an Albian age. The base of the section is not known, since the rocks lie in an overthrust sheet and rest with fault contact on late Tertiary (Báucarit) conglomerate (Fig. 4). Toward the east, they are overlain unconformably by early Tertiary lavas. Strata of post-Albian age are absent in the region studied but may crop out farther north in the same mountain range.

The Palmar formation crops out in a belt half a mile to 2 miles wide and 15 miles long, on the crests of the mountains east of the valley of Sahuaripa, the highest point of which is Cerro el Palmar (Pl. 1). The formation has been thrust westward upon a faulted slice of the Potrero formation (Fig. 4-A, B, and C). The following section shows the principal subdivisions of the formation on Cerro el Palmar (Fig. 4-B):

	Feet
5. Alternating shale, thin-bedded quartzite, and limestone, occurring on crest and east slope of mountain	1250
4. Massive bluish limestone; occurs on western face Cerro el Palmar	2300

3. Thin-bedded shale, sandstone, and dense limestone. Shale contains in places large concretions of dense bituminous limestone and lighter-colored crystalline limestone. Bituminous concretions have *Phylloceras* sp. of Albian type, and lighter-colored concretions show fragments of brachiopods, pelecypods, and corals. The only fossiliferous horizon..... 650±
2. Massive conglomerate with sandy matrix in lower part, calcareous matrix in upper. Cobbles in conglomerate well rounded, mainly of Permian limestone containing abundant fusulinids and crinoid stems. Conglomerate grades laterally into massive bluish limestone of equal thickness, having lenses of conglomerate. This may be basal member of Cretaceous. Exposed near La Parajita..... 1000±
1. Unfossiliferous shaly sandstone, the lowest strata exposed above thrust fault, exposed near La Parajita but absent to north and south, where higher beds lie at base of thrust sheet. Much contorted; may be part of a small separate thrust slice.

The Potrero formation crops out in low hills and valleys east of the high ridge of the Palmar formation and at the base of the Palmar escarpment in a narrow thrust slice.

Near El Potrero the belt of outcrop is 2 miles wide and the formation dips eastward at angles of 35 to 60 degrees (Fig. 4-B). The total thickness exposed is about 5200 feet. West of El Potrerito the basal beds, of andesitic conglomerate, are overlain by quartzite conglomerate, andesitic conglomerate, and agglomerate, then by limestone and shale, andesite flows (at El Potrerito), thin-bedded buff limestone, clay shale, and, at the top, sandy shale. The upper beds of the section are overlain uncomformably on the east by Tertiary lava flows. No fossils were found in the formation in this section.

An outlier of the formation on Cerro de las Conchas (Fig. 4-A), 1½ miles long and less than half a mile wide, is isolated by erosion from the main outcrop in the valley to the east. The strata here consist of fossiliferous marl, buff limestone, quartzose conglomerate, and some andesitic flows or beds of tuff.

North of the Cerro de las Conchas the outcrop of the Potrero formation apparently widens, and the underlying Palmar formation pinches out along the mountain front near the 29th parallel, so that the escarpment is made up of Potrero strata. This section was not studied by the writer, but it appears to be very thick. From a distance, parallel lines of northeastward-dipping hogbacks are seen to extend from the mountains on the west to the divide between the Río de Sahuaripa and the Río de Haros drainage on the east. Post-Albian strata may occur in the upper part of this section.

The thrust slice of the Potrero formation west of the Palmar escarpment is half a mile wide west of La Parajita and consists of sandy limestone, conglomerate, and andesitic flows, all of which are strongly and irregularly folded. At the west foot of Cerro de las Conchas, the beds are abundantly

TABLE 4.—*Cretaceous rocks of Sonora, western Chihuahua, and adjacent areas*

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
32.	E side of valley of Sahuaripa (Co-ord D-II)					
	(a) General characteristics	*Potrero formation:* Shale, thin-bedded brown limestone, some interbedded andesite and agglomerate	Certain horisons contain rich middle Albian fauna	About 5,200 feet	Occurs overlying Palmar beds on E side of Palmar escarpment and in thrust slices at base of the escarpment	
		Palmar formation: Mainly limestone, with shale and quartzite interbedded in upper part, shale and sandstone in lower, with coarse conglomerate at base	In lower third of formation are *Phylloceras* sp. of Albian type and fragments of other invertebrates	About 5,200 feet	Forms high escarpment culminating in Cerro el Palmar, exposure ½ to 2 miles wide and 15 miles long. *See* Figure 4	
	(b) San Miguel	*Potrero formation:* Brown slabby limestone, partly calcareous shale, dense limestone, agglomerate, and conglomerate	Not found	Not measured	Apparently two distinct thrust slices of Potrero present, intruded to E by diorite. *See* Figure 4-C	
	(c) Cerro de las Conchas	*Potrero formation:* Marl, limestone, conglomerate, andesite, and tuff	Middle Albian fauna (*see* text)	Not measured	Conglomerate in Palmar formation here does not appear to occur at equivalent interval below Potrero on Cerro el Palmar; sequence here may be broken by faulting	
		Palmar formation: On E face hill is conglomerate of limestone cobbles having Permian fusulinids	Not found in matrix	Not measured		
	(d) Thrust slice S of Cerro el Palmar	*Potrero formation:* At Cerro Sotoludo, buff, thin-bedded sandy limestone underlain conformably by 130 feet of andesitic flows	Not found	At Cerro Sotoludo 800 feet	Thrust slice is 5 miles long and rarely over 1 mile wide; exposure to N interrupted by a lobe of Palmar limestone extending W across it. *See* Figure 4-A	
	(e) Thrust slice W of La Parajita	*Potrero formation:* Shale, sandy to pure limestone, and andesitic flows	Rich middle Albian fauna (*see* text)	1,272 feet measured		This includes Arivechi fossil locality discovered by Rémond (1866, p. 252)
31.	Guaynopita district (Fig. 1)	Bluish, crystalline and semi-crystalline limestone with interbedded layers of schist; overlain, possibly unconformably, by andesite flows and breccias	Not found	Undetermined	Limestone strongly folded; both sedimentary rocks and andesite flows intruded by granite	Described by Hovey (1907, p. 421-423); limestone believed by Hovey to be Cretaceous, and as andesites are folded equally with limestones but unconformable below younger lavas they are believed to be pre-Tertiary

30. Dolores (Co-ord F-II)	Chloritic schist	Not found	Undetermined	Vertically laminated, strike NE; exposed on bank of Arroyo de Dolores	Described by Hovey (1907, p. 426)
29. Río Moris, near Navosaigame (Co-ord F-III)	Limestone boulders	Not found		Boulders in stream, suggesting outcropping of Cretaceous limestone upstream	Noted by Hovey (1907, p. 433)
28. E side Río Moris between Moris and Ocampo (Co-ord F-III)	Massive bluish-gray limestone and some associated porous, red-brown quartzite	Not found	Undetermined	Exposed on steep eastern side of gorge, overlain by NE-dipping andesite flows; thrust W upon younger rocks. *See* Figure 5-B	
27. Sahuayacán-La Trompa area (Co-ord E-III & IV)	At Santa Teresa mine near Sahuayacán, exposures of black fissile shale with thin limestone beds, altered to a chlorite schist near fault to W, overlain with apparent conformity by andesites. In gorge of Arroyo Sahuayacán, escarpment SE of La Trompa (Pl. 4, fig. 1), and valley of Río Mayo, exposures of quartzite, carbonaceous slate, and some limestone	In limestones 1 mile N of El Zapote, King found three fragmentary unidentifiable fossils, apparently ribbed ammonoids of Mesozoic aspect	Undetermined	Area of exposure 15 miles in length; cut off to N by rhyolitic intrusive, to S by granite intrusion; thrust to SW upon younger volcanic rocks. *See* Figure 5-C	*See* Bagg (1905, p. 750) and Treadwell (1905, p. 1213); some of the quartzites and carbonaceous slates in the region may be of Barranca age
26. El Piloncillo (Co-ord E-III)	Calcareous schist	Not found	Undetermined	Isolated exposure near rhyolite intrusions. *See* figure 5-C	
25. Arechuybo area (Co-ord E-IV)	On W side of area massive blue-gray limestone with some interbedded quartzite, on E quartzite and slate	Not found	Undetermined	N-S belt of sedimentary rocks in contact with granite to W, overlain to E by andesite flows	
24. Area NW of Chínipas (Co-ord E-IV & V)	Section on W flank of anticline (*See* plate 5, section 10): 6) Tertiary agglomerate, unconformable on underlying beds 5) Shale, mostly gray and sandy in upper part, dark gray and fissile in lower; limestone concretions in some beds. 1,000 feet. 4) Massive limestone 3) Red sandstone and dark gray to reddish shale, with nodules of hard, dark-gray limestone. 300 feet or more 2) Well-bedded gray limestone. 50 feet 1) Quartzite and andesite flows; base not seen On E side of area is white granular limestone in high hogback; may be bed 4	Bed 4 of section is full of shells of a large *Exogyra*, whose cross sections are seen on surface. In float are rhynchonellids (?) and worm tubes in addition. Fossils common but difficult to collect because of hardness of rock	About 2,000 feet exposed	Sedimentary area 3½ miles wide, having generally anticlinal structure, but with many minor folds and a small diorite intrusion, overlain to E and W by Tertiary lavas and agglomerates dipping away from sedimentary rocks. *See* Figure 5-D	First described by Botsford (1911, p. 706). Beds 1 to 4 of section may be equivalent to Palmar formation, bed 5 to Potrero

TABLE 4.—*Cretaceous rocks of Sonora, western Chihuahua, and adjacent areas*—Continued

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
23.	Taimuco (Co-ord E-V)	White marble and quartzite, containing pockets of gypsum	Not found	About 100 feet	Small area in bottom of valley, surrounded by lava and underlain by granite	First noted by Botsford (1911, p. 705). Small areas of limestone also reported by Botsford near Texcalama and about one mile S of Los Camotes
22.	Bahuérachic-Macoribo area (Co-ord F-V)	Hard bluish limestone in large area near Bahuérachic; between Bahuérachic and Macoribo, quartzite, slate, and limestone; W of Macoribo bluish andesite	Less metamorphosed parts of limestone contain *Ezogyra*	Undetermined	Limestone forms prominent peak at Bahuérachic; andesite W of Macoribo forms high range with W-facing scarp	
21.	Lluvia de Oro area (Co-ord F-V & VI, G-VI)					
	(a) Lluvia de Oro (Co-ord F-VI)	Section by Burrows with additional notes by King: 7) Andesite, containing included boulders of limestone 6) Massive gray limestone, altered locally to an epidotized marble. 250 feet 5) Fossiliferous limestone, exposed near mouth of Lluvia de Oro mine. 20 feet 4) Thin-bedded limestone. 300 feet 3) Slate and limestone. 100 feet 2) Thin-bedded sandstone. 100 feet 1) Intrusive diabase extending several thousand feet down slopes of adjacent canyons	*Rhynchonella lacunosa* and poorly preserved belemnites collected by Burrows, identified by Aguilera; inhabitants of area reported ammonoid found in limestone quarry near mine in about 1908, but later lost	Over 750 feet	Ridge of limestone trends N-S for several miles, cut off on W by fault, overlain to E by volcanic rocks intruded at base by diabase. *See* Figure 5-E.	*See* Burrows (1907; 1908) and Tays (1910); assigned to Jurassic by Burrows on determination of *Rhynchonella lacunosa*. (*See* text.)
	(b) San Francisco del Río (Co-ord F-VI)	Limestone	Poorly preserved rhynchonellids	Undetermined	Forms ridge trending N-S, thrust eastward on diorite	
	(c) Gloriapán (Co-ord F & G-V)	Hard bluish limestone	Not found	Undetermined	Thrust southward upon andesite	
	(d) Piedras Verdes (Co-ord G-V)	Light-gray limestone	Not found	Undetermined	Small exposure dipping NE and intruded by diorite	
	(e) La Cienaguita (Co-ord G-V)	Light-gray granular limestone	Has silicified markings that may be rudistids	About 10 feet	Occurs in two small knobs near bottom of narrow valley	

20. Urique (Co-ord G-V)	Highly mineralised slate and quartzite; limestone reported in mine half a mile N of Urique	Not found	Undetermined	Area of about ½ square mile surrounded by andesite	Burckhardt (1930, p. 83) reports ammonoid from black shale SW of Urique, locality vaguely described and probably not one of those shown on map (Plate 1)
19. Area E of Guaycora (Co-ord D-II)	At top, andesite and agglomerate, underlain successively by quartzite interbedded with andesite, yellowish thin-bedded limestone, massive bluish limestone, bluish limestone conglomerate, and shale	Not found	Undetermined	Exposed along crest of range, forming a belt 2½ miles wide, overlain unconformably to E by Tertiary lavas; to S area of outcrop narrows by overlap of Tertiary beds, only small exposures of andesite and agglomerate being there associated with plutonic rocks. *See* Plate 1, section B-B	Massive limestone and conglomerate at base of section may be equivalent to Palmar, overlying strata to Potrero
18. Between Sahuaripa and Bacanora (Co-ord D-I)	Red and gray shale, calcareous shale, and hard gray and bluish limestone	Not found	Undetermined	Dips SW at low angle	Noted by Aguilera (1896-1897, p. 121)
17. Mina México area (Co-ord D-II)	Sedimentary section of which most prominent member is a black, sub-crystalline limestone	Not found	About 1,000 feet		Described by Hynes (1912, p. 280)
16. Puerto el Dátil-El Astillero range (Co-ord D-II)					
(a) Between Cervantes and Guaycora	From top down are successively conglomeratic quartzite, andesite, thin-bedded limestone, and banded slate and quartzite; Barranca quartzite at base	Not found	Undetermined	Section dips irregularly eastward, overlain unconformably by basalts of Báucarit formation	
(b) Escarpment W of El Astillero	Andesite flows and tuff containing a few layers of limestone near Campo del Yaqui, El Astillero, and La Palma; Barranca formation at base	Not found	Undetermined	Section dips eastward, overlain unconformably by Tertiary lavas. *See* Figure 6-C	
15. Sásachic (Co-ord D-II)	Massive bluish limestone	Not found	Undetermined	Forms narrow ridges flanked by intrusions of granite	May be equivalent to Palmar
14. W of Sásachic (Co-ord D-II)	Andesite and agglomerate with some associated sandstones and thin limestones	Not found	Undetermined		
13. Cervantes (Co-ord D-II)	Massive limestone, andesite, and agglomerate	Not found	Undetermined	Occurs on E side of Arroyo Tibursari	Limestone may be equivalent to Palmar

TABLE 4.—*Cretaceous rocks of Sonora, western Chihuahua, and adjacent areas*—Continued

No.	Locality	Lithology	Fossils	Thickness	Extent and structural relations	Remarks
12.	El Carrizal area (Co-ord D-II)	Andesite flows, agglomerate, and conglomerate, with several beds of limestone 1½ to 3 feet thick in lower part near El Carrizal; Barranca formation at base in one locality	Limestone beds contain silicified worm tubes and obscure opalized remains of other fossils	Undetermined	Dip E, overlain unconformably by Tertiary lavas at Puerto el Jobeo; same beds occur E of Puerto el Jobeo at Agua Honda	
11.	El Recodo-La Dura area (Co-ord C-III)	Andesite and agglomerate, some thin sandstones and limestones	Not found	Undetermined	Faulted to NW upon Báucarit formation	
10.	Sierra de San Javier (Co-ord C-II)	Andesite flows; according to Dumble, in southern sierra the Barranca is overlain unconformably by silicified conglomerate and breccia, which may be base of Cretaceous volcanic rocks	In road cut in andesite agglomerate near La Barranca Dumble (1901b) found embedded remains of large oyster shell, altered to calcite	Undetermined	Occur in various small areas, commonly in valleys surrounded by high ridges of quartzite; quartzite near contact much shattered; andesites may be windows in thrust sheet or down-faulted. *See* Figure 3-A	
9.	S and SW of Sierra de San Javier (Co-ord C-II & III)	Andesite and agglomerate; in Arroyo Obispo, 5½ miles W of Ónavas, is 75 feet of thin- to medium-bedded light-gray limestone resting on agglomerate and overlain by andesite flows. *See* Plate 5, section 8	From limestones in Arroyo Obispo Dumble (1901a) collected Cretaceous fossils (*see* text)	Probably over 3,000 feet	Extend from S end Sierra de San Javier S probably to Río Yaqui, in places intruded by granite	
8.	Range W and NW of San Juan de Güisa (Co-ord C-II)	Andesite; near San Juanico are sandstone and conglomerate which are only slightly indurated but cut by granite dikes	Not found	Undetermined	Forms high range, intruded to W by granite	
7.	Río Yaqui E of Cumuripa (Co-ord C-III)	Andesite flows, angular andesite agglomerate, andesitic and some rhyolitic tuff, and sandstone, part quartzitic. ½ mile NNE of Tufanito is a hard black limestone 50 feet thick, between layers of andesite	Not found	Undetermined	Occurs in several belts of outcrop; 2½ miles S of Cumuripa andesites and quartzites altered to phyllite along contact with granite intrusion. Base of succession, resting on pebbly quartzite of the Barranca, exposed on ridge 1 mile W of Agua Salada. W of Agua Caliente, volcanic rocks are overlain by rhyolite tuff of possible Tertiary age; elsewhere the next highest beds are Báucarit conglomerate	

6. NE base of Sierra de Baroyeca (Co-ord C & D-IV)	Dark-gray weathered andesite	Not found	Undetermined	Underlies Tertiary volcanic rocks capping sierra	
5. Sierra de Álamos (Co-ord D-V)	Andesite flows	Fossils locally reported to occur here; not seen by King	Undetermined	Dip SW beneath Tertiary volcanic rocks capping sierra; intruded by granite at base	Limestones reported locally at ranch of Tepuxtete NW of Álamos; not located by King. Botsford (1911, p. 704) reports limestone W of El Tábelo
4. Cerro Lista Blanca (Co-ord B-III)	Andesitic flows, tuff, agglomerate, and conglomerate, probably resting on upper quartsites of Barranca formation	Not found	365-490 feet		Described by Dumble (1900a, p. 143-144) and regarded by him as Triassic. *See* text
3. La Colorada district (Co-ord A & B-II)	Hornblende andesite flows, in Zubiate area resting on Permian limestone, in Sierra de Moradillas on Barranca formation	Not found	Not measured	Crops out in parts or all of several mountains, in smaller hills, and over extensive parts of pediment areas, generally capped by Tertiary (?) volcanic rocks. *See* Figure 6-D	Hornblende andesite mapped by Flores (1929, p. 114-115) in this area considered by him to be intrusive; writer's observations in area less detailed, but lines of parting between flows, and other evidence of volcanic origin seen
2. S end Sierra de Cobachi (Co-ord B-II)	Andesites	Not found	Undetermined	Cover large area W and N of Noria de Pesqueira, intruded toward SE by granite	
1. Between Horcasitas and Santa Ana					
(a) Mina la Sultana NE of Horcasitas (Figure 1)	At top gray and blue fossiliferous limestone; below, conglomeratic sandstone containing pebbles of quartzite and felsite; at base quartzite of unknown age, possibly Barranca	*Exogyra* and other imperfectly preserved fossils; age Neocomian according to Burckhardt	Undetermined		Reported by Flores (1929, p. 151-152) and Burckhardt (1930, p. 150)
(b) Cerro de Lumbrera and Sierrita de la Pima, near Santa Ana (Figure 1)	Thin beds of shale, brownish fossiliferous limestone, and gray, bluish, and black limestone. *See* Plate 5, section 4	Trigoniids of austral type, *Ctenostreon* sp., and *Exogyra* sp.; trigoniids indicate Neocomian age	Undetermined		Reported by Flores and Burckhardt

fossiliferous; it is, in fact, probably the richest Cretaceous fossil locality in all Sonora. The spot was discovered by Rémond (1866, p. 252). His statement that the fossiliferous beds are underlain by sandstone and overlain by limestone is, however, incorrect. The sandstone is the Báucarit

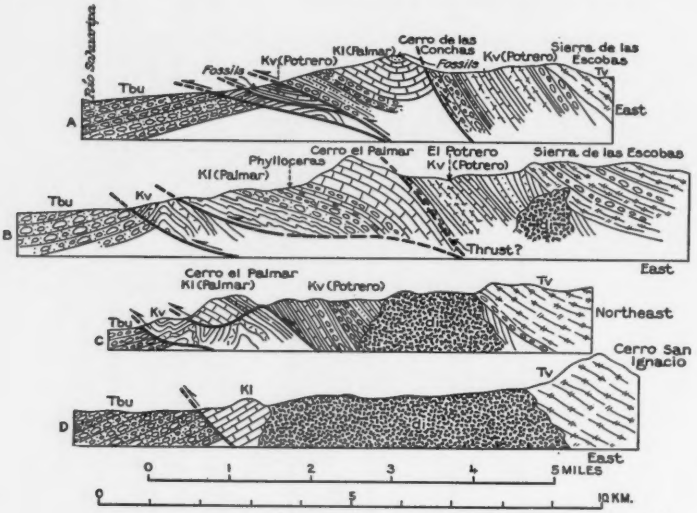


FIGURE 4.—*Sections of Cretaceous rocks*

On east side of valley of Sahuaripa, near Arivechi (Co-ord D-II). (Kl) Palmar formation; (Kv) Potrero formation; (Tv) early Tertiary volcanic rocks; (Tbu) upper member of Báucarit formation; (di) diorite.

formation, and the limestone Palmar; the strata have attained their present apparent sequence as a result of thrust faulting (Fig. 4-A).

The section at the fossil locality is as follows:

	Thickness (Feet)
Palmar formation: Massive bluish limestone, conglomerate, and andesite, poorly exposed on slopes covered with heavy brush.	
Overthrust contact on beds below	
Potrero formation:	
(13) Sandy limestone	48
(12) Nodular limestone and shale	118
(11) Massive bluish limestone	141
(10) Nodular limestone (Sill 29 feet thick)	15
(9) Nodular blue limestone with rare *Trigonia* and *Exogyra* (Flow or sill 45 feet thick)	75
(8) Fossiliferous clay shale	174
(7) Shale with thin limestone laminae	105
(6) Nodular blue limestone with echinoids	10
(5) Nodular buff limestone	24
(4) Fossiliferous clay shale	256

	Thickness (Feet)
Overthrust contact on beds below	
Potrero formation:—Continued	
(3) Alternating sandy hard limestone and nodular marly limestone.....	40
(2) Bluish-black, highly fossiliferous, calcareous shale, containing thin layers of nodular limestone. The best locality for collecting is in a flat saddle between two gullies.....	261
(In the upper part of Unit No. 2 a sill 16 feet thick is not included in the thickness given.)	
(1) Sandy gray limestone, cut by calcite veins.....	5
Covered	
Báucarit conglomerate	
Total thickness of section	1272

The sills are a part of a system of andesitic dikes and sills that cut the formation in this vicinity, but some of the supposed sills may be contemporaneous lava flows.

The position in the Potrero section of the shales at the fossil locality is somewhat in doubt, on account of the complex structure. The different lithology of the beds in the outlier at the top of the Cerro de las Conchas, which contain the same fauna, with slight differences in facies, may be the result of an unlike facies at the same horizon in the two thrust sheets, or the fossils may range through a considerable thickness.

The fossils collected by Rémond from below Cerro de las Conchas were studied by Gabb (1869) and have since been referred to as the Arivechi fauna. The collections of the writer were studied by Mr. W. S. Adkins, who also had access to Gabb's original types. Mr. Adkins has kindly furnished the list of species in Table 5, with notes on their occurrence in related strata of other areas.

According to Adkins, *Gryphaea mucronata* Gabb, originally described from here, is synonymous with the so-called narrow variety of *Gryphaea marcoui* Hill and Vaughan, a Fredericksburg marker. The Grayson marker commonly called *Gryphaea mucronata* is a new species.

Adkins states that the Potrero fauna is definitely of Fredericksburg or middle Albian age and is of submarginal facies. The same association of fossils occurs in beds of Albian age in southwestern New Mexico (Sarten sandstone); at the Cerro de Muleros, west of El Paso, Texas; at the Sierra de la Encantada near the Río Conchos in northeastern Chihuahua; along the southeastern border of the Llano Estacado of West Texas; and in Oklahoma and Kansas (Kiowa shale). These resemblances are indicated in columns V, W, X, and Y of Table 5.

The section east of the valley of Sahuaripa correlates with part or all of the Bisbee group of southeastern Arizona and northeastern Sonora. Perhaps the Palmar limestone is equivalent to the Glance and Morita clastic formations and the portion of the Mural limestone which contains Glen Rose (lower Albian) fossils. It probably correlates with the 2850-

TABLE 5.—*Arivechi fauna*

List of species	Arivechi, Sonora							Related strata				
	A	B	C	D	E	F	G	V	W	X	Y	Z
Echinoidea:												
Tetragramma (*Diplopodia* ?) *malbosi* (Aguilera)							x					
Phymosoma texanum (Roemer)		x	x	x	x	x		x	x			x
Pseudopyrina parryi (Hall)?						x						
Pliotoxaster sp. indet				x	x							x
Corals:												
Parasmilia texana Roemer		x		x	x	x		x				x
Worms:												
Serpula sp. 1 and 2						x						
Ammonoidea:												
Phylloceras sp. aff. *forbesianum* D'Orbigny	x											
Beudanticeras n. sp					x							
Engonoceras gabbi Böhm		x	x		x	x						
Pelecypoda:												
Avicula pedernalis (Roemer)						x						x
Cardita alticosta Gabb (*C. arivechensis* Heilprin ?)		x		x	x	x						
Cucullaea inermis Gabb		x	x		x	x				x	x	
Exogyra texana Roemer		x	x		x	x		x	x	x	x	x
Granocardium sabulosum Gabb		x	x	x	x	x						
Gryphaea mucronata Gabb		x			x	x						x
Leptosolen ? sp. indet		x			x			x	x	x		x
Mutiella roblesi Böse		x	x					x				x
Ostrea sp						x						
Pecten (*Neithea*) *irregularis* Böse					x			x			x	x
P. (*Neithea*) *occidentalis* Conrad					x							x
Pholadomya sonorensis Gabb		x				x						
Protocardia granulifera Gabb		x	x			x						x
Pinna aff. *breweri* Gabb						x						
P. sp. aff. *guadalupae* Böse		x			x			x				x
P. sp. indet. (square)		x	x		x							
Rémondia furcata Gabb		x	x		x	x						
Tapes gabbi Böse		x		x	x	x						x
Trigonia mooreana Gabb		x	x	x	x	x						x
Gastropoda:												
Amauropsis pedernalis (Roemer)						x		x				x
Anchura sp						x						
A. kiowana Cragin					x						x	
Aporrhais ? *monolifera* (Gabb)		x			x	x						
Cerithium sp		x										
C. mexicanum Gabb					x	x						
Cinularia rectilabrum Gabb		x				x						
Delphinulum cingulatum Gabb		x				x						
Fusus mexicanus Gabb						x						
Lunatia aff. *praegrandis* (Roemer)		x										
L. sp. (round)			x									
Pseudomelania zebra (Gabb)		x				x						
P. texana (Roemer)						x						x
Tylostoma tabulatum Gabb		x	x		x	x						
T. mutabile Gabb		x	x		x	x						x
Turritella belvederii Cragin		x		x	x					x	x	

TABLE 5.—*Arivechi fauna*—Continued

List of species	Arivechi, Sonora							Related strata				
	A	B	C	D	E	F	G	V	W	X	Y	Z
Gastropoda:—Continued												
T. bravoensis Böse	...	x	...	...	x	...	...	x	...	...	...	...
T. aff. *marnochi* White	...	x	...	...	...	...	...	...	...	...	...	x
T. aff. *seriatim-granulata* Roemer	...	x	...	...	x	x	...	...	...	...	...	x

(A) Palmar limestone: Concretions in shale overlying basal conglomerate of formation; west slope of Cerro el Palmar.
(B) Potrero formation: Beds 2 to 5 of section, west base of Cerro de las Conchas (number 17264).
(C) Potrero formation: Beds 6 and 7 of section, west base of Cerro de las Conchas (number 17263).
(D) Potrero formation: Beds 8 and 9 of section, west base of Cerro de las Conchas (number 17267).
(E) Potrero formation: Outlier of formation on top of Cerro de las Conchas (number 17265).
(F) Reported by Gabb, from collections made by Rémond, probably from about the same places as localities B, C, D, and E.
(G) Reported by G. Cotteau (1890, p. 294). Not verified by King and Adkins.
(V) Cerro de Muleros, west of El Paso, Texas.
(W) Sierra de la Encantada, Chihuahua.
(X) Llano Estacado area, Texas.
(Y) Kansas (chiefly Kiowa shale).
(Z) Fredericksburg of Central Texas.

foot section described by Imlay (1939, p. 1734) near El Tigre, northeastern Sonora (Fig. 1), consisting of interbedded shale, sandstone, and limestone which contain a late Aptian or early Albian fauna. The Palmar is probably also equivalent to the whole Trinity section of the Little Hatchet Mountains of southwestern New Mexico. These correlations cannot be made on the basis of common faunas but rather on stratigraphic position. The Potrero formation may be equivalent to the upper portion of the Mural and to the Hay Flat formation, both of which contain Fredericksburg faunas.

In the barranca section of the Sierra Madre Occidental province east and south of the exposures in the Sahuaripa district, the ages and relations of the sedimentary rocks are far less definite. The region is a plateau composed predominantly of slightly disturbed Tertiary volcanic rocks, and the older sedimentary rocks which formed the floor on which they were spread out appear at the surface only as small inliers.

At all places the sedimentary rocks lie below the general level of the plateau summits, and the deep erosion of the barrancas has uncovered them. Also, the floor on which the volcanic rocks were laid down seems to have been markedly irregular in places, so that some of the outcrops of the underlying sedimentary rocks are the projecting summits of old ridges. Examples are at Guaynopita (Fig. 1) and near Lluvia de Oro

(Co-ord F&6-V, F-VI), where limestone peaks are higher than the base of the surrounding volcanic rocks. Many exposures of sedimentary rock are due, however, to uplift. The outcrops northwest of Chínipas (Co-ord E-IV&V) lie along the crest of a dome-like fold which has also tilted the

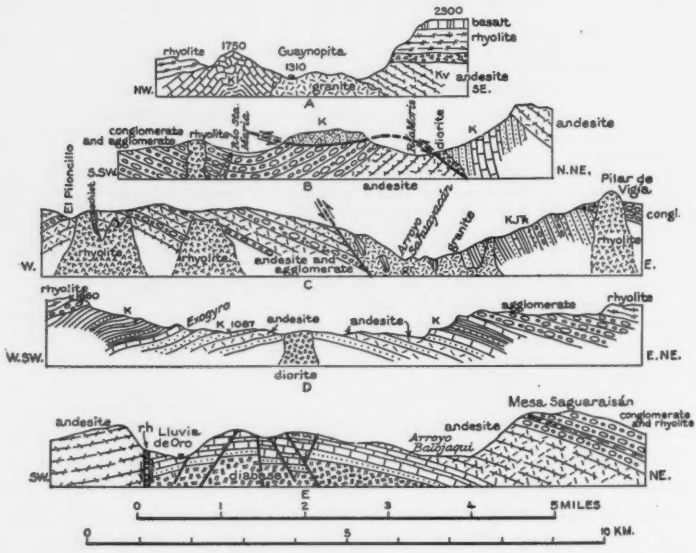


FIGURE 5.—*Sections in western Sierra Madre Occidental of Chihuahua*

Showing relationships of the Mesozoic rocks.

(A) Guaynopita district (redrawn from section by Hovey). (B) Area east of Moris (Co-ord E&F-III). (C) Sahuayacán district (Co-ord E-III). (D) Northwest of Chínipas (Co-ord E-IV&V). (E) Lluvia de Oro district (Co-ord F-V&VI) (after Burrows, with some additions by the writer). (K) Cretaceous; (KJTr) undifferentiated Cretaceous and Barranca formation. The volcanic rocks are probably mostly of early Tertiary age, but some, as (Kv) in Figure A and the andesite in Figure D, are probably of Cretaceous age. Heights in meters.

volcanic rocks along the flanks. A number of other areas, notably those to the east and west of Moris (Co-ord E&F-III), whose outcrops are elongated north and south, have been raised by faults, along which the strata are thrust westward and southwestward over the volcanic rocks.

At Guaynopita massive limestones predominate but are associated with slate and quartzite. At Sahuayacán west of Moris (Co-ord E-III), most of the rocks are quartzites and slates. The rocks are intruded by granite and diorite, and all are more or less metamorphosed.

The writer believes that most of the sedimentary rocks in the region are of Cretaceous age. As noted, some of the carbonaceous slates and

quartzites may be of Barranca, or Triassic-Jurassic age. A few intensely metamorphosed fossils found northwest of Chínipas, at El Zapote (Co-ord E-IV), Urique (Co-ord G-V), and Bahuérachic (Co-ord F-V) and ammonoids reported by other collectors prove little more than a Mesozoic or possible Cretaceous age. The limestones near Lluvia de Oro (Co-ord F-VI) contain rhynchonellids and belemnites. They were assigned by Burrows (1908) to the Jurassic because of the presence of *Rhynchonella lacunosa* Castillo and Aguilera, originally described from a zone in the Sierra de Catorce, San Luis Potosí, and regarded as Upper Jurassic. Kellum (1936, p. 1068-1069) reports *Rhynchonella lacunosa* and belemnites from a faunal zone west of Torreón, Durango. Imlay (1938, p. 1684-1685) notes general Valanginian resemblances and some Berriasian or Tithonian elements. The fauna is probably of earliest Cretaceous age. Possibly *Rhynchonella lacunosa* has a longer range than previously supposed, or, in the Catorce section, the zone of *Rhynchonella lacunosa* may be Lower Cretaceous. The writer believes present evidence favors Cretaceous classification of the Lluvia de Oro limestones. Rhynchonellids also occur in the Cretaceous beds northwest of Chínipas. If the *Rhynchonella lacunosa* zone is Berriasian or Valanginian, the Lluvia de Oro limestones are older than the lowest fossiliferous beds of the Palmar formation.

Overlying the sedimentary rocks at some places, a thick sequence of andesite flows is succeeded by undoubted members of the Tertiary volcanic succession. The writer suspects that a part of the andesites is of Cretaceous age. Supporting evidence was found by Hovey (1907, p. 421-423) at Guaynopita, where such andesites are as steeply tilted as the supposed Cretaceous limestone and are overlain uncomformably by gently tilted later volcanic rocks (Fig. 5-A). Elsewhere, however, the evidence is less definite, and a separation could not be made in reconnaissance work. For convenience such volcanic rocks of possible pre-Tertiary age are described with the early Tertiary rocks.

Province of parallel ranges and valleys.—West of the excellent Sahuaripa section of the Cretaceous, between the Río de Sahuaripa and the Río Yaqui, rocks of probable Cretaceous age are exposed, but so far no fossils have been found.

A limestone unit, possibly equivalent to the Palmar formation, occurs at the base of the Cretaceous in the first range west of the Río de Sahuaripa and in the northern part of the second range to the west (Pl. 1). Southward, the limestone either wedges out or grades into a clastic and volcanic facies similar to the upper part of the Cretaceous section. At all localities the limestone is metamorphosed, and in the western range it is

invaded by extensive masses of granite, above whose pediments it rises in steep ridges.

The overlying beds include quartzitic sandstones, agglomerates, and dense, dark-colored andesite flows, with the proportion of volcanic material increasing westward. The rocks are strongly folded and faulted, so that dips vary from a few degrees to nearly vertical, and the outcrops of the rocks alternate irregularly with those of the underlying Barranca formation. Northeast of Guaycora in the eastern range, near El Carrizal and Los Pilares (Co-ord D-II), and probably at other places, the titled clastic and volcanic rocks are overlain unconformably by less steeply tilted Tertiary lavas, which rise in mesas and plateaus.

In the Sierra de San Javier (Co-ord C-II) are some small outcrops of andesite, probably of Cretaceous age, as along the Arroyo los Tarahumares, east of San Javier, and farther north at Guayacán. Dumble (1900a, p. 140; 1900b, p. 11) reports that in the southern part of the sierra the upper massive quartzite member of the Barranca formation is overlain unconformably by silicified conglomerate and breccia; this may be the basal member of the volcanic succession. In a road cut in andesite agglomerate near La Barranca Dumble (1901b) found the embedded remains of a large oyster shell, now altered to calcite.

South and southwest of the Sierra de San Javier are extensive exposures of andesites, which probably extend nearly unbroken southward to the Río Yaqui, although the intervening area was not studied. Their thickness may exceed 3000 feet (Pl. 5, section 8). In Arroyo Obispo (Co-ord C-III) they dip gently eastward and in places show a spheroidal structure. Five and a half miles west of Ónavas, gray limestone 75 feet thick crops out in the arroyo. It rests on agglomerate and is overlain by andesite flows. From the limestone, Dumble (1901a) collected silicified pseudomorphs of numerous oysters, a small *Gryphaea*, a few gastropods, *Cyprimeria*, and plates of a large echinoid which he considered to be of Cretaceous age. On the Río Yaqui, half a mile north-northeast of Tufanito, beside the railroad, hard black limestone 50 feet thick lies between andesite flows.

In the southern part of the province of parallel ranges and valleys, near the Ríos Mayo and Cedros, rocks believed to be of Cretaceous age occupy relatively small areas. They consist, as farther north, of andesite flows and agglomerates, with some interbedded quartzitic sandstones. By contrast, the Tertiary volcanic rocks of the area are predominantly rhyolitic or basaltic. The rocks are extensively intruded by granites. Some of the smaller areas are mere inclusions, rising as hills from extensive pediments carved from the granites which inclose them.

Central Sonora.—In many of the mountain ranges west of the Sierra de San Javier, andesite flows having a total thickness of about 1000 feet rest on the eroded surface of the Barranca formation and in places on the Paleozoic limestones; these would seem to be the western equivalent of the probable Cretaceous volcanic rocks already described.

This is the type area of Dumble's Lista Blanca formation, named for Cerro Lista Blanca (Co-ord B-III), which lies

"a few miles southwest of the town of San Marcial, and is plainly distinguished from Ortiz by a prominent point that juts out from its face" (Dumble, 1900a, p. 143-144).

Dumble applied the name widely in Sonora to the older, andesitic volcanic rocks, which he considered to be Triassic. The underlying Barranca formation is now known to contain Lias fossils in its upper part, so that the Lista Blanca is certainly Jurassic or younger. Moreover, Dumble found Cretaceous fossils in a limestone interbedded in the volcanic rocks south of the Sierra de San Javier, and the writer has found volcanic rocks interbedded in the fossiliferous Cretaceous rocks of the Sahuaripa district, showing that the pre-Tertiary volcanic rocks are of Cretaceous rather than Triassic age. With further detailed work it may prove desirable to extend Dumble's term Lista Blanca to Cretaceous volcanic rocks east of the type locality. Cerro Lista Blanca is slightly south of the area studied by the writer. At present, there is some uncertainty as to whether the volcanic rocks of the type locality are not actually of Tertiary age.

According to Dumble, the following section is exposed on Cerro Lista Blanca:

	Feet
7. Andesitic flows, at whose base is a black lava, almost glassy in texture. In it, a great spheroidal structure not less than 40 feet across is perfectly outlined on the face of the bluff	50
6. Tuff	30
5. Brown vesicular lava, whose cavities are filled by secondary quartz	30
4. Agglomerate and slaty andesite	50
3. Tuff, with tuffaceous agglomerate in lower part	100
2. Andesitic agglomerate	30
1. Volcanic conglomerate, with lenses of tuff abundant toward top. The conglomerate contains angular to rounded boulders of andesite agglomerate, porphyritic andesite, hornblende andesite, gray vesicular lava, and slate	75–200
Base concealed; near-by are exposures of the upper quartzites of the Barranca formation.	

Early Cretaceous of northern Sonora.—Between Horcasitas and Santa Ana (Fig. 1) limestones and shales (Pl. 5, section 4) contain a fauna older than that of the Palmar formation and older than the lowest fossiliferous Cretaceous of the Bisbee section, which is not older than Aptian. The following fossils were collected near Santa Ana by Flores (1929, p. 151-152) and identified by Burckhardt (1930, p. 150): *Trigonia* aff. *hertzogi* Haussmann, *T.* cf. *ventricosa* Krauss, *T.* cf. *subventricosa* Stan-

ton, *Trigonia*, sp., *Ctenostreon* sp., and *Exogyra* sp. The trigoniids are said to be of austral type and to indicate a Valanginian or basal Hauterivian age.

Cretaceous of northeastern Sonora and southeastern Arizona.—In various ranges between El Tigre in northeastern Sonora (Fig. 1) and the Bisbee district of southeastern Arizona, sections of Cretaceous strata crop out. Exposures in Sonora have been studied by Dumble (1900a, p. 135-137), Taliaferro (1933, p. 16-23), and Imlay (1939). Cretaceous sections in southeastern Arizona have been described by Ransome (1904b, p. 5-7), Darton (1925, p. 135-138), and Stoyanow (1936b, 1936c, 1937, and 1938). The subdivisions and character of the Cretaceous succession in the Cabullona and Bisbee areas are shown in sections 2 and 3, Plate 5.

The writer (King, 1934, p. 91; Schuchert, 1935, p. 147) has suggested correlation of the Glance and Morita formations at the base of the Bisbee Mesozoic section with the Barranca formation of central Sonora, because of their lithologic similarity and similar stratigraphic position upon the Permian limestone. Recent studies by several workers in southeastern Arizona, southwestern New Mexico, and northeastern Sonora have proved this correlation incorrect. In the upper part of the Morita formation, Stoyanow (1937) found *Ostrea ragsdalei* and *Glauconia branneri* of Trinity age. Three zones containing Trinity trigoniids and ammonoids occur in the Bisbee section throughout 900 feet of strata between the Morita and the overlying Mural limestone.

"Evidence of continuous oscillatory conditions and frequent interruptions marked by the clastics with land plants is seen through the entire lower half of the sequence" (Stoyanow, 1938). Lasky (1938) has shown that in southwestern New Mexico clastic members lithologically similar to the Morita occur at various horizons in a thick Trinity section, with intervening limestone members, probably in part of reef origin, similar to the Mural. Imlay (1939, p. 1734) shows that in the Cañón de Santa Rosa, southeast of El Tigre, northeastern Sonora (Fig. 1), basal Cretaceous strata with an upper Aptian or lower Albian fauna rest directly upon Permian limestones. The Cretaceous beds at this locality may be marine equivalents of the lower part of the Bisbee group. These facts show that in the type section at least the upper portion of the Morita contains a Trinity fauna, that essential unity of the entire group is indicated by regional intergradation of a Glance-Morita clastic facies of Trinity age with a Mural calcareous facies, and that lower Mesozoic formations are absent between the Carboniferous and the Cretaceous in northeastern Sonora.

Volcanic rocks have been reported among rocks believed to be of Lower Cretaceous age in the Courtland-Gleeson region northeast of Bisbee

(Wilson, 1927, p. 21-22). Here thin andesite flows occur in a thick clastic succession. Intense Lower Cretaceous volcanism in southwestern New Mexico is shown by the section in the Little Hatchet Mountains (Lasky, 1938). Evidence of Upper Cretaceous volcanism has been recorded in the Cabullona basin of northeastern Sonora (Pl. 5, section 3), where the Camas sandstone is tuffaceous and the highest member of the Cretaceous section is a rhyolite tuff 800 feet thick, which appears to form part of a conformable sequence with the underlying formations. In the Christmas region, near the Gila River in southeastern Arizona, several thousand feet of andesitic lavas and pyroclastic rocks are interbedded in their lower part with sandstones, shales, and several coal beds. The sedimentary rocks contain Upper Cretaceous plants and invertebrates (Campbell, 1903; Ross, 1925a, p. 11-14; Ross, 1925b, p. 25-28). These are overlain unconformably by younger, probably Tertiary, volcanic rocks.

Paleogeographic relations.—The Berriasian or Valanginian limestones at Lluvia de Oro are the oldest Cretaceous strata known in the area studied. These and the Valanginian or Hauterivian rocks of northern Sonora may have been deposited during the initial transgression of the Cretaceous sea from the southwest.

Rocks of Albian age were evidently much more widely distributed. On the east side of the valley of Sahuaripa the Albian is represented by a marine fossiliferous facies, with andesitic lava interbedded in the upper part. The same facies probably extends to the south and east, where metamorphosed limestones, possibly correlative with the Palmar formation, crop out as inliers surrounded by Tertiary volcanic rocks. These in turn may be continuous beneath the cover of volcanic rocks with the thick limestones of Albian age that form many of the mountain ranges in northeastern Chihuahua.

The shore line of the Cretaceous sea evidently extended northward through central Sonora, being generally in the western part of the present province of parallel ranges and valleys, but with periodic floods extending farther west. Volcanic rocks increase in proportion toward the west and southwest, either because of overlap upon the marine strata or replacement by the volcanic facies. The interbedded sedimentary rocks thin as the lava flows thicken, so that west of the Río Yaqui the section consists almost wholly of volcanic rocks. All the older volcanic rocks of central Sonora, therefore, are probably of Lower Cretaceous age.

North of Sahuaripa, the Albian strata probably extended unbroken to the Bisbee district of southern Arizona, and numerous outcrops may still remain in the intervening area. The north-trending shore line of central Sonora evidently turned northwestward in the vicinity of Santa Cruz

(Fig. 1). In the northern portion of the Lower Cretaceous geosyncline great oscillations in level seem to have taken place, with deposition of great thicknesses of clastic sediments at the beginning of the sequence and periodically throughout the Albian, as a result of recurrent uplift of the margins of the basin. Coarse clastic rocks and in places volcanic rocks alternate with fossiliferous limestones. This is best exemplified in the exceptionally thick section of the Little Hatchet Mountains of New Mexico (Lasky, 1938, p. 538-540). The northern shore line of the lower Albian (Trinity) sea probably lay near and at times within the northern part of this range. Here at several times erosion cut deeply into the rocks that had been deposited and lithified in the same epoch. The Trinity movements there were accompanied by intense volcanism, which centered near the edge of the geosynclinal basin.

The middle Albian (Fredericksburg) extended somewhat farther north, being represented by the Sarten sandstone north of the Trinity shore line. The fauna of this formation resembles that of the Potrero beds of Sonora. The same fauna occurs even farther northeast, for fossils which occur in it are found in a littoral facies of the middle Albian that apparently extended as far as southern Kansas.

There appear to have been two more or less distinct times of Cretaceous volcanism in the southwestern United States and northwestern Mexico. The first, of which there is evidence in the Sahuaripa district, the Little Hatchet Mountains, and possibly the Courtland-Gleeson district, is of Lower Cretaceous age. The second, for which evidence is found in the Cabullona, Christmas, and Silver City (Paige, 1916, p. 12) districts, and perhaps elsewhere, is of Upper Cretaceous age, and probably late Upper Cretaceous.

No record of post-Albian time exists in the area studied by the writer, but the presence of Upper Cretaceous strata in northern Sonora and adjacent parts of southern Arizona and New Mexico suggests that they may have extended into the region.

EARLY TERTIARY VOLCANIC ROCKS

General features.—During early Tertiary time in the southwestern United States and Mexico, great floods of lava poured out upon a surface of folded Cretaceous and older rocks. A group of andesite and rhyolite flows and tuffs, some flows of basalt, and thick clastic deposits, composed chiefly of fragments of volcanic material in the area studied, is believed to have originated at this time. The group rests with marked unconformity upon the Cretaceous rocks, which also contain great amounts of volcanic material, and is overlain by the Pliocene (?) Báucarit formation.

The early Tertiary volcanic rocks present a greater variety of composition than both the Cretaceous and the later Tertiary volcanic rocks but in general they are more acid; the older are chiefly andesitic, whereas, in the early Tertiary, there are also considerable thicknesses of rhyolite and some flows of basalt. There is a well-marked unconformity in many places between the two groups, and the Cretaceous volcanic rocks are more strongly folded. The early Tertiary rocks are distinguished from the overlying Báucarit formation by a dominance of volcanic material, whereas the latter, although containing some basalt flows, is dominantly terrestrial. The early Tertiary volcanic rocks precede, and the Báucarit formation follows an important epoch of mid-Tertiary diastrophism, in which the mountains began to take on their present outlines, and which was accompanied by the intrusion of great masses of plutonic rock. The two are therefore separated by a marked unconformity, and the overlying Báucarit contains a greater variety of fragmental material, including granite detritus.

The early Tertiary volcanic rocks are very thick under the Sierra Madre Occidental but they thin considerably westward. In the province of parallel ranges and valleys they consist of thick rhyolite flows and west of the Sierra de San Javier of thin flows associated with pyroclastics and conglomerate. There is considerable variation from place to place in the succession of the different types of component rocks, even in sections rather closely adjacent. The volcanic rocks probably originated from fissures, the locations of which are not known. Dikes cutting the older volcanic rocks may have been the source of younger flows.

At a number of places there are thick beds of sandstone and volcanic conglomerate in the middle and upper part of the volcanic group. Some of these are overlain by rhyolitic lavas and may be of about the same age. Such conglomerates are found near Moris (Co-ord E-III), Navosaígame and Pinos Altos (Co-ord F-III), Uruáchic (Co-ord F-IV), and Chínipas (Co-ord E-V). At Uruáchic there are also a few limestone cobbles. Sandstones near Yécora (Co-ord E-III) are probably higher in the succession and are here overlain by no younger beds. Farther west, at La Colorada (Co-ord A-II), conglomerate underlies the youngest rhyolite. In places these sandstones and conglomerates resemble those of the later Tertiary Báucarit formation, and some of them may be of Báucarit age. Most of them are, however, overlain by rhyolites and other younger volcanic rocks and are not associated with basalts such as characterize the Báucarit, so that they are here considered older.

Named subdivisions—Hovey (1907, p. 432-433) introduced the name Navosaígame conglomerate for an early Tertiary thick clastic member

in the vicinity of Ocampo (Co-ord F-III). The writer did not visit the type locality of this formation. Possibly the Navosaígame is a time unit and correlative with the early Tertiary conglomerates which are extensively developed in the barranca section. Moreover, the volcanic rocks below the Navosaígame and similar volcanic conglomerates may be wrongly classed by the writer as Tertiary and may actually be of Cretaceous age. This is perhaps suggested by the generally andesitic character of the volcanic rocks below the conglomerates, in contrast to the more acid composition of those above. Botsford (1911, p. 705) states that there is an angular unconformity between the upper rhyolites of the volcanic sequence and the underlying andesite and interbedded clastics in the Chínipas district. If further evidence should cause reclassification of the volcanic rocks here placed in the early Tertiary, then the Navosaígame would become a basal clastic member of the Tertiary.

Farther west, Dumble (1900a, p. 126-132) divided the Tertiary volcanic and clastic section into the Trincheras, Nogales, and Báucarit formations, largely on lithologic distinctions. The first two had their type localities in northern Sonora, and the third within the area of this paper. The Báucarit, as traced by the writer from its type locality, is a useful formation unit, comprising the later Tertiary clastic rocks and associated basalt flows. The two older divisions are less definite. Their type localities are far from central Sonora, and it seems hardly possible, as pointed out by Weed (1902, p. 429), to separate the volcanic sequence into time units over wide areas when the sole basis of distinction is lithologic.

Distribution.—The early Tertiary volcanic rocks are best developed in the Sierra Madre Occidental province. They are gently tilted or flat-lying over wide areas, although somewhat faulted in the western part (as shown in sections on Plate 1). North of Yécora (Co-ord E-III) and Ocampo (Co-ord F-III) they extend across a plateau almost continuously for a long distance eastward from the escarpment on the east side of the valley of Sahuaripa. Here the volcanic rocks dip generally eastward at angles up to 30 degrees, the more resistant flows forming high, even-crested mesas and east-sloping dip plains. The succession is repeated along the lines of several widely spaced faults, downthrown to the west. The youngest rocks of the group occur to the east, where the folding is gentle and elevations higher. South of Yécora and Ocampo the structure is somewhat more complicated. The rocks have been broadly folded, and in the barranca section zones of thrust faulting bring up pre-Tertiary sedimentary rocks and intrusive plutonic rocks. Deep

FIGURE 1. TUFFACEOUS SANDSTONE
Bank of Río Arañas, a short distance west of Temóchic (Co-ord G-III)

FIGURE 2. BLUFFS OF ANDESITE AND INTERBEDDED TUFF
South side of Río de Oteros, south-southeast of Uruáchic (Co-ord F-IV)

EARLY TERTIARY VOLCANIC ROCKS

gorges or barrancas trench the volcanic rocks in this region, exposing as much as 6600 feet of section in their valley slopes.

Farther west, in the province of parallel ranges and valleys, the early Tertiary volcanic rocks are more irregularly distributed, as they are infolded and infaulted with a great variety of older rocks and intruded in places by masses of granite and diorite. They rest unconformably on older Cretaceous andesites and in places upon pre-Cretaceous rocks. In the vicinity of the intermontane valleys they dip beneath basalt flows and conglomerates of the Báucarit formation. In the southern part of the province the early Tertiary volcanic rocks rise as high, stratified mesas or pinnacled crests above the hills of older rocks.

In central Sonora, the most extensive area of probable early Tertiary volcanic rocks is in the ranges north and south of La Colorada (Co-ord A-II). These mountains have a cuesta-like form with east-facing scarps (Figs. 3-B and 6-D). Most of them are capped by a rhyolite flow 165 feet thick, underlain by 100 feet of sandstone, conglomerate, tuff, and breccia. These rest on hornblende andesite flows of possible Cretaceous age which crop out on the slopes below. The largest of the mountains is the Sierra del Chivato south of La Colorada, but there are others northward from La Colorada toward Zubiate, generally separated by areas of alluvium. The early Tertiary rocks of the La Colorada area have been described by Flores (1929, p. 109-110, 115-116).

The early Tertiary volcanic and associated clastic rocks in different areas are described in Table 6; the microscopic character of rock specimens collected at seven localities, as determined by Mr. Ward Smith, is also given.

BÁUCARIT FORMATION (LATE TERTIARY)

General features.—The name Baucari division was applied by Dumble (1900a, p. 126-128) to

> "sands, clayey sands, and conglomerates of extremely even bedding . . . well developed in the vicinity of the town of Baucari on the Cedros River" (Co-ord D-V).

The writer has corrected the spelling to Báucarit and considers the unit to be a formation. Dumble's correlations away from the type locality are not entirely in harmony with those of the writer, since beds here assigned to the Báucarit in the Yaqui valley were classed by Dumble as "Nogales division", and those near Agua Caliente on the Río Mayo (Co-ord D-V) as "Lista Blanca division". The strata called "basin deposits" by Hovey (1907, p. 425-429) in the Tutuaca valley (Co-ord F-II) are probably the same as the Báucarit formation, and the formation is more or less equivalent to the Gila conglomerate in southern Arizona.

TABLE 6.—*Early Tertiary volcanic and clastic rocks of Sonora and western Chihuahua*

No.	Locality	Section exposed	Microscopic character	Extent and structural relations	Remarks
29.	Between Río de Sahuaripa and Tarachic (Co-ord D & E-II)				
	(a) Between El Potrero and Tarachic	Lower, andesite and rhyolite flows resting unconformably on Cretaceous; upper, white to reddish rhyolite and tuff, overlain unconformably near Tarachic by Báucarit conglomerate	From SE of Agua Blanca a specimen of andesitic pumice; consisting of minute anhedral crystals of quartz in a matrix of partly devitrified glass, in which faint outlines of shards and bubbles are still visible; index of glass nearly equal to that of Canada balsam, suggesting andesitic composition; rock silicified	Basal Tertiary volcanics on Sierra de las Escobas dip 30° ENE; underlying Potrero beds of Cretaceous dip 55° ENE. *See* Figure 4-A and B	
	(b) Between Cerro San Ignacio and La Iglesia	Lower volcanics, forming Cerro San Ignacio, are rhyolite; overlain to E by alternating rhyolite and andesite flows, with some interbedded agglomerate, tuff, sandstone, and shale		Tertiary rhyolite, mineralized by diorite intrusion, forms Cerro San Ignacio. *See* Figure 4-D	
	(c) E of Güisamopa	Lower part andesite, overlain by escarpment of rhyolite tuff 3500 feet high, capped by Báucarit beds; E of El Trigo de Cororepe is high plateau of rhyolite, which is underlain at El Trigo by rhyolite tuff, and near Agua Blanca by slightly consolidated conglomerate		Downfaulted area of Báucarit interrupts sequence of upper part. *See* Pl. 1, section C-C′	
28.	Mulatos area (Co-ord E-II)	Lower part, to W, andesite, overlain to E by alternating rhyolite and andesite flows and tuffs; town of Mulatos surrounded by bluffs of reddish rhyolite; E of Mulatos a long high lava mesa (Sierra de Santa Bárbara)		Lowest beds upfaulted E of Tarachic valley, highly mineralized along fault scarp; to S, between Tayopa and Mulatos, volcanics intruded and mineralized by diorite. *See* Pl. 1, section C-C′	
27.	Dolores (Co-ord F-II)	Section at Dolores, descending eastward: 4) Acidic tuff, dipping ENE. 650 feet Erosional unconformity 3) Rhyolite, including both lithoidal and obsidian flows, dipping SW. 325 feet 2) Diabase, probably extrusive, cut by siliceous and rhyolitic dikes. 460 feet 1) Basalt and breccia. 800 feet At base, pre-Tertiary chlorite schist		Bed 2 contains veins of Dolores mine	Not visited by King; description after Hovey (1907, p. 424)

26. W side Mesa de Venado, E of Dolores (Co-ord F-II)	Section E of Arroyo Calaveras: 5) Andesite; the top of the mesa over wide areas is formed of dull brownish augite andesite. 260 feet 4) Rhyolite. 130-165 feet 3) Andesite or dacite. 500 feet 2) Rhyolitic or dacitic flows. 650–730 feet 1) Lithoidal and glassy rhyolite, in massive flows, some obsidian, cut by basic dikes. Thickness undetermined but probably great		W of base of steep scarp in Arroyo Calaveras, Hovey noted occurrence of rhyolite, agglomerate, and andesite, but these dip SW, and King believes them downfaulted	Description after Hovey (1907, p. 426)
25. Sierra Oscura and Río Babanore (Co-ord D & E-III & IV)				
(a) Sierra Oscura	Sierra is capped by basalt; below are two resistant ledge-forming members of andesitic pumice with basalt between; section well exposed on W near El Metate, and on southeastern spurs of range, where 5000 feet of flows is exposed	Specimen of upper ledge-forming member from between Curupaco and El Metate is andesitic pumice consisting of microcrystalline quartz in aggregates and radiate clusters, in a glassy matrix showing faint flowage lines, shards, and collapsed bubbles. Specimen of lower ledge-forming member from same locality is andesitic pumice consisting principally of turbid glass, with poor flowage structure, made up of shards and collapsed bubbles, and containing occasional fragments of quartz crystals, and lenses of anhedral quartz grains. The glass in the two rocks has an index near that of Canada balsam, hence they are probably andesitic. Both rocks have been welded, silicified, and partly devitrified	Sierra Oscura is high plateau wholly composed of low-dipping early Tertiary volcanics, on W bordered by steep scarp. *See* Pl. 1, section D-D'	
(b) Babanore valley (Co-ord E-III)	Youngest rocks are basalt flows with some interbedded sandstone and conglomerate, capping Mesa Polvosa and Mesa de la Porra, and extending down slopes of barranca to a resistant ledge-forming member of andesitic pumice; below pumice are basalt flows, than a great thickness of andesite flows and andesitic pumice.		Río Babanore flows in a great barranca 3000 feet deep, with narrow inner gorge below lower ledge of andesitic pumice. *See* Figure 6-B	

TABLE 6.—*Early Tertiary volcanic and clastic rocks of Sonora and western Chihuahua*—Continued

No.	Locality	Section exposed	Microscopic character	Extent and structural relations	Remarks
	(c) Yécora valley (Co-ord E-III)	Upper conglomeratic sandstones underlain 3 miles N of Yécora by scarp-forming rhyolite and rhyolite tuff which continue northward to El Trigo de Cororepe		Upper sandstones surround alluvial valley of Yécora, dipping into it at low angle	Rhyolitic volcanics below upper sandstones N of Yécora contrast with basalts below same horizon to the S of Yécora
24.	Sahuayacán and Moris area (Co-ord E-III)	At top, E of Moris, mesa-forming rhyolite tuff; below, non-resistant conglomerate composed of fragments of igneous rocks, over 650 feet thick, underlain by andesitic agglomerate; W of Moris the conglomerate is probably unconformable on Cretaceous volcanics		Conglomerate has synclinal structure; cut by numerous dikes and irregularly shaped intrusive masses of rhyolite. *See* Figure 5-B	Conglomerate here probably correlates with the Navosaígame conglomerate of Hovey
23.	Navosaígame (Co-ord F-III)	*Navosaígame conglomerate.*—Thick dark blue or bluish-green coarse conglomerate alternating with whitish, fine-grained, hard conglomerate and beds of dark red sandstone. Beds seem to be composed entirely of material of igneous origin. No limestone boulders seen. Rhyolites at rim of Moris canyon rest on upturned edges of conglomerate		Cut by many dikes, some basic, some apparently acid	Description from Hovey (1900, p. 432–433)
22.	Ocampo area (Co-ord F-III)	Massive dark-gray andesite and diabase flows, tuff, and some conglomerate, exposed at and W of Ocampo, underlain on E side Río Moris gorge by massive andesite conglomerate, which rests on pre-Tertiary		Dip gradually decreases from 45° on W to about 10° near Ocampo; andesite flows and tuff contain principal metalliferous veins of Ocampo district	Hovey (1907, p. 434-435) correlated a conglomerate near bottom of canyon with the Navosaígame, but Linton (1912) and King found this to be a thin and probably local clastic member. The whole sequence at and W of Ocampo may be Cretaceous, but no unconformity noted with overlying flows
21.	Pinos Altos (Co-ord F-III)	*Navosaígame conglomerate.*—Dark blue and dark red conglomerate and sandstone derived entirely from basic igneous rocks, interbedded with diabase. Overlain by rhyolites and tuffs dipping at lower angle, succeeded upward by andesite flows, then diabasic sheets		Diabase dikes cut both the stratified rock and overlying rhyolite tuff	Description by Hovey (1907, p. 438–439)

20. E and N of Ocampo (Co-ord F-III)	Plateau of flows and tuffs, largely rhyolitic, resting on andesitic beds of Ocampo area. Section by Hovey (1907, p. 435) on trail from Ocampo to crest of range to E: 10) Rhyolite flows and tuffs. 650 feet 9) Andesitic tuffs and flows. 525 feet. Unconformity 8) Coarse, dark-red, cross-bedded conglomerate and sandstone. 250 feet 7) Diabase. 400 feet 6) Andesite flows. 65 feet 5) Rhyolite tuffs and flows. 460 feet. Unconformity 4) Gray conglomerate and dark thin-bedded sandstone (tuff?). 180 feet 3) Diabase agglomerate. 50 feet 2) Diabase flows. 500 feet 1) Conglomerate		E of Ocampo there is change from monoclinal E dip to gentle warping, so that upper rhyolite flows and tuffs cover a large area, and the underlying volcanics are exposed only in deeper gorges. Most spectacular exposure of upper rhyolite tuffs is at Cascada de Basaseáchic below which is exposed 1300 feet in a sheer wall, with almost no trace of bedding (Pl. 3). (Pl. 1, section D-D′)	
19. Between Basaseáchic and Miñaca (Co-ord F & G-III; Fig. 1)	Between Basaseáchic and Temóchic, upper beds of plateau are agglomerates, tuffs, and sandstones, with some interbedded rhyolite flows; E of Temóchic these are overlain by basalts at least 625 feet thick, apparently the youngest volcanics of region, which extend E to W side basin of Miñaca, where they rest on augite andesite			*See* Pl. 6, Figure 1. Additional details on this area are given by Hovey (1907, p. 440–442)
18. Between Arechuybo Uruáchic (Co-ord E & F-IV)	Highest ridges near Uruáchic are capped by light-colored volcanics which may be rhyolite or rhyolite tuff; below are andesite flows and tuffs (*see* Plate 6, figure 2), then thick soft reddish conglomerates with well-rounded cobbles, some of which are of limestone and quartzite; lower part of section is thick sequence of andesite, agglomerate, and tuff, resting to W on pre-Tertiary rocks		Conglomerate occurs at and a short distance W of Uruáchic, seemingly down - faulted against lower andesites on W; also on N side of Río de Oteros S of Uruáchic; lower andesite is plicated into many gentle folds	
17. Chínipas area (Co-ord E-IV & V)	At top, rhyolite flows and tuff, containing interbedded sandstones and conglomerates of well-rounded fragments between Chínipas and Las Chinacas; below are reddish and gray sand, soft shale, and glomerate with much interbedded andesite, succeeded downward by a thick group of andesite flows and agglomerates, then rhyolite and andesite flows; at base on flanks of pre-Tertiary uplift NW of Chínipas is agglomerate, at Naranjo conglomerate		Upper rhyolite and tuff form bluffs on each side of valley at Chínipas, forming high summits of plateau to W and projecting westward toward Mayo valley on spur ridges; medial conglomerates underlie valley of Río Chínipas near Chínipas. *See* Figure 5-D and Pl. 1, section E-E′	Upper rhyolite and tuff may be equivalent to similar volcanic capping plateau E of Ocampo. Botsford (1911, p. 705) states that rhyolites rest unconformably on underlying andesite and clastics; estimates thickness of andesite group at 2000 feet or more

TABLE 6.—*Early Tertiary volcanic and clastic rocks of Sonora and western Chihuahua*—Continued

No.	Locality	Section exposed	Microscopic character	Extent and structural relations	Remarks
16.	NE of La Junta (Co-ord F-VI)	Andesitic lavas, underlain by soft reddish sandstone and agglomerate with some interbedded flows		Upper andesites form high mesas E of Río Chinipas; clastics extensive near Los Molinos	
15.	Lluvia de Oro area (Co-ord F & G-V & VI)	At top soft conglomerate containing thin flows of rhyolite, underlain by thick massive andesites and andesitic agglomerate		Conglomerate forms high escarpment of Mesa de Saguaraisán. *See* Figure 5-E	
14.	Urique area (Co-ord G-V)	At top, rhyolites, which contain quartz spherulites and geodes on top of ridge ESE of Cuiteco; underlain by reddish-weathering andesite and agglomerate with a few interbedded rhyolite flows, 3250 feet or more thick		Upper rhyolites cap plateau between Urique and Cuiteco; lower section exposed on steep slopes of valleys of Urique and Cuiteco	
13.	Tierra Blanca-El Encinal area (Co-ord D-II)	Rhyolite, andesite, and basalt flows, with some interbedded tuff, resting unconformably on Cretaceous volcanics on W and overlain unconformably by Báucarit formation to E; in Tierra Blanca area reddish and white tuff predominate		E of El Encinal low-dipping Tertiary volcanics form mesas	
12.	Puerto el Jobeo area (Co-ord DII)	Rhyolite tuffs, unconformable on Cretaceous volcanics			
11.	E flank Sierra de San Javier (Co-ord C-II)	Between Tónichi and San Antonio de la Huerta, the following section: At top indurated brown conglomerate, underlain successively by thick andesite agglomerate, thick flow of white rhyolite, and andesite flows and agglomerates at base		Tertiary volcanics dip in general ENE, overlain to E by Báucarit conglomerate	Lower portion of this section may include some Cretaceous volcanics
10.	E of Agua Salada (Co-ord C-III)	Rhyolite tuff			
9.	Flanks of Río Chico valley near Movas (Co-ord D-III)	Rhyolite and rhyolite tuff, with some interbedded andesite and agglomerate		E of Movas are high ridges of Tertiary volcanics, having sharp pinnacles and pierced rocks along the crest	
8.	NW of Tezopaco (Co-ord D-IV)	White and reddish lavas, probably rhyolitic, with some agglomerate and andesite			
7.	La Travesada (Co-ord D-IV)	Rhyolite		Small isolated inliers surrounded by Báucarit basalt	
6.	Espíritu (Co-ord D-IV)	Rhyolite and andesite		Exposed on the flanks of an anticlinal uplift	
5.	Sierra de Baroyeca-Cerro Huitates (Co-ord C & D-IV, D-V)	Massive andesite, much silicified and fractured, weathering to great reddish bare surfaces	Sections of three specimens from Mina de Baroyeca show that rock consists of phenocrysts of plagioclase (An_{28}) 2 to 4 mm. in diameter, in a microcrystalline groundmass composed mostly of plagioclase in minute laths, arranged	The massive andesite caps Sierra de Baroyeca; toward SE a lower range of the same rocks forms the castellated crests of Los Pilares and the reddish ridge of Cerro Huitates	Dumble (1900a, p. 140) appears to have regraded the silicified andesites of the Sierra de Baroyeca erroneously as Barranca quartzite

		in fluidal pattern; groundmass partially silicified, and phenocrysts show slight sericitization		
4. Cerro Zaporaa range (Co-ord C-IV & V)	Rhyolite (?)		Forms high range standing in bare pinnacles overlooking coastal plain	
3. Sierra de Álamos (Co-ord D-V)	Light-colored lava		Forms sheer scarp on NE side of range	
2. Range E of Tepahui and Quiriego (Co-ord D-IV & V)	Rhyolite and andesite	Specimen of andesite porphyry on Casita-Mójari trail near crossing of large arroyo has phenocrysts, comprising 15% of rock, of zoned crystals of plagioclase (An_{30}) up to 3 mm. in diameter, of basaltic hornblende, and of augite; matrix consists of minute crystals of plagioclase, hornblende, and augite, in a turbid glass, whose index is near that of Canada balsam, minute feldspar laths showing fluxion pattern; rock has been somewhat altered by introduction of carbonate in the feldspar phenocrysts and of quarts in veinlets and clustered aggregates. Specimen of silicified ansite from Cerritos Colorados consists of microcrystalline quarts and feldspar, with some fine grains of biotite and other dark minerals; parts of slide show faint flowage structure; outlines of a few small phenocrysts preserved, although original crystals are entirely replaced by opal		Andesite capping Cerritos Colorados erroneously described by King (1934, p. 100) as an altered limestone
1. La Colorada area (Co-ord A-II)	At top rhyolite flow 165 feet thick underlain by sandstone, conglomerate, tuff, and breccia, 100 feet, which rest on andesite flows, probably Cretaceous		*See* Plate 1, section A-A′	Volcanics between La Colorada and San Javier are wholly classed on map an Báucarit basalt; a part of these may be of early Tertiary age

The Báucarit formation, as here defined, consists of slightly indurated, well-bedded sandstones, conglomerates, and some clays. The conglomerates contain chiefly rounded to subangular fragments of the older volcanic rocks but in places they include many of granite and some of limestone (Pl. 7, fig. 2). In the lower part of the formation, where fully developed, there are one or more basalt flows, interbedded with basalt agglomerate. These are not exposed in the vicinity of the type locality, but since they are an integral and conformable part of the succession they are considered by the writer to be a lower member of the formation. The lower basaltic member is shown by a different pattern from that of the upper conglomeratic member on the geologic map (Pl. 1).

The formation is distinguished from the older Tertiary rocks in that the latter are principally volcanic, with lava flows that are generally more acid and that vary greatly in composition. The clastic deposits interbedded in the older Tertiary are dominantly of pyroclastic origin. Most of the included fragments are poorly rounded and have been derived from volcanic rocks. By contrast, the sedimentary portions of the Báucarit formation are not derived directly from volcanic eruptions, although they include sorted and reworked fragments of the older volcanic rocks and they contain material derived from lower rocks, including for the first time in the sequence pebbles and boulders of granite. At most places the unconformity between the Báucarit and the older rocks is well marked, although at a few localities no perceptible break was observed between them.

Distribution and structure.—The Báucarit formation is most widespread in the province of parallel ranges and valleys. It occurs rarely in the northern part of the barranca section of the Sierra Madre Occidental and has been recognized in only two places in the plateau section. In central Sonora the conglomerates of the Báucarit formation are not widely exposed, although they may underlie a part of the alluvium-sheeted pediments. There are some areas here of basaltic lava, which appear to be the youngest volcanic rocks in the region. Some of these may be as old as Báucarit time, but others, which are comparatively fresh, are evidently much more recent.

The formation crops out generally in intermontane depressions, where it has been worn down to gently sloping pediments. In places, particularly in the southern part of the area, it spreads out over the low mountain ridges and has been considerably uplifted. In such regions it is dissected into sheer cliffs and pinnacles. Dips in the formation rarely exceed 25 degrees and are generally much less. At many places the formation is faulted against the older rocks and in the northern part of the

province of parallel ranges and valleys it is overridden along thrust faults by the rocks of the bordering mountains (Fig. 3-C and D, Fig. 4). Generally, the eastern sides of the valleys are downfaulted, but the lower Báucarit rises high on the slopes of the ranges bordering these valleys on the west.

Table 7 describes the Báucarit formation at different localities in Sonora and bordering states.

Mode of deposition.—The folding and faulting of the Báucarit formation might suggest that its present position in the valleys results from preservation from erosion by downfolding and downfaulting, and that it might formerly have extended over much of the region. The stronger disturbance of the underlying beds and the presence in the formation of granite and other rocks from the cores of the ranges suggest, however, that its present areas of outcrop mark approximately the outlines of the original basins of deposition. The conglomerates of the formation were probably laid down as alluvial-fan deposits along the margins of the uplifted ranges. The finer-grained, even-bedded deposits

TABLE 7.—*Báucarit formation of Sonora and western Chihuahua*

No. Locality	Lithology	Extent and structural relations	Remarks
20. Cedros valley and area E of Álamos (Co-ord D-IV & V, E-V & VI)	Upper member: Thick bedded to massive conglomerate (Plate 7, Figure 1) containing pebbles and boulders, mostly subrounded, of acidic igneous rocks in arkosic matrix, interbedded with sandstone of igneous detritals, having distinct, even bedding planes and rare cross-bedding. Lower member: One or more intermediate flows interbedded with conglomerate. NE of Conocárit flow is 20 meters thick, of biotite dacite with phenocrysts of zone plagioclase (An_{48}) and quartz up to 1 mm. in diameter, most of which have embayed outlines, and smaller grains of biotite; groundmass is turbid brown glass with index less than that of Canada balsam, crowded with crystallites in spherulitic arrangement. Lava flows apparently absent SE of Río Mayo.	Formation exposed in long, narrow belt, on W side dropped down against older rocks by a series of en echelon faults, on E side resting with sedimentary contact on early Tertiary volcanic and older rocks. Upper member has greatest extent. Lower member exposed on Cerro Moyahui, S of Chirimoco, and 3 miles NE of Conocárit, where it forms NW-striking hogback ridge	At base, formation is seemingly unconformable upon older rocks in most places, but SE of Río Mayo at El Tábelo and between El Sabino and Las Plomosas the early Tertiary andesites are overlain with apparent conformity by hard, angular agglomerate, then soft sandstone and well-rounded conglomerate typical of the Báucarit
19. Range between Tezopaco and Curupaco (Co-ord D-IV)	Lower member: Basalt flows and basalt agglomerate	Lower member forms entire range, with few inliers of older rocks; forms broad anticline. *See* Plate 1, section D-D′	

TABLE 7.—*Báucarit formation of Sonora and western Chihuahua*—Continued

No. Locality	Lithology	Extent and structural relations	Remarks
18. Ranges N and W of Baroyeca (Co-ord C & D-IV)	Upper member: Conglomerate and sandstone Lower member: Basalt flows	Near Mútica the basalts form a line of mesas sloping W toward valley of El Volador, in places dissected to form high buttes	
17. Range N of Cerro Zaporaa (Co-ord C-IV)	Lower member: Basalt flows	Range formed partly by upwarping and partly by faulting	
16. Ciudad Obregón-Navojoa area (Co-ord C-IV & V)	Lower member: Basalt flows	Detached, low black hills, dipping SW toward coast, partly buried by alluvium	
15. Los Camotes area (Co-ord E-V)	Shale, igneous detrital sandstone, and conglomerate having well-rounded fragments of andesite, granite, and limestone up to 16 inches in diameter	Area of exposure small; beds highly disturbed; high range of Sierra Madre province lies to E	
14. Valley of Sahuaripa (Co-ord D-II)	Upper member: Sandstone and conglomerate Lower member: Basalt flows and agglomerate, resting unconformably on older rocks on flank of western range	Upper member occupies most of lower parts of valley, the beds dipping gently toward center of valley from each side, downfaulted to E (Figure 4); to W lower member rises in line of scalloped cuestas, its width of outcrop broadening southward, where it forms gently sloping mesas S of El Encinal, deeply trenched by arroyos. *See* Plate 1, section B-B′.	Pilares west of El Valle de Tacupeto are outliers of basalt and agglomerate forming steep-sided buttes. El Arco is natural bridge formed of basal agglomerate of Báucarit
13. Valley of Bacanora (Co-ord D-II)	Upper member: Conglomerate, standing in high mesas NE of Guaycora Lower member: Basalt with interbedded conglomerate	Beds downfaulted on E, upper member occurs in eastern part valley N of Guaycora, lower member to S and W of Guaycora. *See* Plate 1, section B-B′	Near Mina México, Hynes (1912, p. 281) reports exposures 100 feet or more thick, of consolidated conglomerate, in part steeply inclined resting unconformably on underlying sedimentary rocks, and containing one or more lava flows in places
12. Los Pilares area (Co-ord D-II)	Conglomerate (Figure 6-C; Plate 7, figure 2)	Outlier, complexly infaulted among older rocks, rising in scarp eroded to vertical bastions, with two high, sharp conglomerate buttes rising from lower slopes	
11. La Dura-Rebeico valley (Co-ord C-II & III)	Upper member: Bedded conglomerates (Plate 8, figure 2) containing cobbles of volcanic rocks, and in places cobbles of granite; NE of La Dura a rhyolite flow interbedded; upper member seemingly conformable with early Tertiary volcanic rocks W of Tónichi Lower member: Poorly developed in this area; basaltic lava associated with conglomerate occurs W of Ónavas and La Dura	Beds dip at low angle E from older rocks of Sierra de San Javier; on E side valley downfaulted against eastern range. *See* Plate 1, sections A-A′ and C-C′	
10. Valley of Río Chico (Co-ord D-III)	Upper member: Sandstone and conglomerate Lower member: Basalt flows	Upper member occurs W and N of outcrop of lower; structure of valley synclinal	

TABLE 7.—*Báucarit formation of Sonora and western Chihuahua*—Continued

No.	Locality	Lithology	Extent and structural relations	Remarks
9.	Puerto de la Matanza area (Co-ord D & E-II)	Sandstone and conglomerate; basalt outliers below to W	Downfaulted area surrounded by early Tertiary volcanic rocks	
8.	Taráchic-Tayopa area (Co-ord E-II)	Lower member: Basalt flows with some interbedded clastic rocks	Elongate belt of outcrop, downfaulted to E	
7.	Mesa de San Augustín (Co-ord F-II)	Sandstone and conglomerate, coarser on western side of area of exposure, with boulders 12 inches or more in diameter of vesicular basalt and smaller subangular fragments of other lavas in a sandy matrix; basalt flow, 130 feet thick, apparently interbedded in sedimentary rocks, occurs about 265 feet above Río Tutuaca; total of about 400 feet of section exposed along Río Tutuaca	E of Dolores, "all stages of the gradual dissection and removal of the basin deposits are seen, from table - topped mountains, typical mesas with flat tops many acres in extent, to shaft - like pinnacles upon rounded bases, and even to entirely denuded mounds, presenting an extremely billowy topography"	Description after Hovey (1907, p. 425); referred to as "basin deposits"
6.	Las Ánimas area (Co-ord F-II)	Mud-cracked sandstone and conglomerate with well-rounded basaltic boulders	Occur in structural basin	Description after Hovey (1907, p. 429); basalts noted in vicinity by Hovey may be lower Báucarit; limits of formation only approximate on Plate 1
5.	San Juan de Güiza-La Palma area (Co-ord C-II)	Conglomerate	Elongate belt of outcrop, downfaulted to E	
4.	Tecoripa - Cumuripa valley (Co-ord C-II & III)	Soft conglomerate with rounded cobbles, interbedded with light-gray sandstone; NE of Cumuripa rests on angular andesitic agglomerate, believed to be Cretaceous, without apparent unconformity	Elongate graben	
3.	Cerro Avispa range, Cerros de Sanguijuela, and N of Noria de Pesqueira (Co-ord B-II)	Basalts, thought to be lower member of Báucarit		
2.	La Colorada area (Co-ord A-II)	Conglomerate and basalt	Conglomerate noted on pediment between La Colorada and Torres, position not determined with sufficient accuracy to shown on Plate 1; basalt flows form small hill between Torres and Luján	
1.	Between Hermosillo and Nogales (Fig. 1)	Coarse-grained conglomerates, with cobbles of andesite, rhyolite, and more rarely slate, granite, and quartzite, in an argillaceous, calcareous, or ferruginous matrix; rest discordantly on Cretaceous strata, granite, and volcanic rocks; overlain in places by tuff, volcanic breccia, or basalt flows, but generally by alluvium; at Planchas de Plata, 12 miles SW of Nogales, conglomerate is red, overlain by basalt and resting upon rhyolitic agglomerate of possible early Tertiary age	Occur in valleys between the mountain ranges, dipping at low angles; conglomerates much jointed near Cucurpe and eroded into striking pillars, windows, and natural bridges	Described by Flores (1929, p. 152–153, 205–206). Conglomerates 6 miles N of Horcasitas, overlain by spherulitic rhyolite, may be of early Tertiary age, correlative with similar conglomerates near La Colorada

may have been of lacustrine origin. Báucarit time was later than the great epoch of Tertiary volcanic activity, but some eruptions continued into the period. The flows of basalt in the lower part of the formation may be absent locally, so that the lower Báucarit is represented in such places wholly by clastic rocks and cannot be differentiated on the areal geologic map.

Fossils and age.—No fossils were found in the Báucarit formation by the writer, but vertebrate remains are reported at a number of places. According to the local people, at a place about 1000 feet east of the town of Baroyeca (Co-ord D-IV), and at some other points near-by, were found a thigh bone 3 feet long, as well as large ribs and teeth. Possible proboscidian bones are reported from terraces along the Arroyo de Mátape south of San José de Pimas (Co-ord B-II) and at Tepeguaje between Ónavas and Toledo (Co-ord C-II). A fossil tooth is reported from the district of Álamos by the Compañía Petrolera de Sonora (Anonymous, 1924). These fossils suggest either a late Tertiary or a Quaternary age for the formation.

The Báucarit formation appears to be part of an extensive series of late Tertiary terrestrial, intermontane deposits, widely developed in northwestern Mexico and southwestern United States. In southern Arizona, the Gila conglomerate is closely related in origin and is probably of nearly the same age (Ransome, 1904a, p. 5-6; 1923, p. 13-14; Darton, 1925, p. 163-165). This underlies most of the intermontane depressions of southeastern Arizona. In the San Pedro valley, not far north of the International Boundary, it is

> "a valley fill now deformed and dissected, but accumulated under arid conditions in enclosed or partly enclosed valleys. The conglomerate of the typical facies encircles unconsolidated fine-grained deposits laid down in the central areas of the original valleys. In the fine-grained deposits a large vertebrate fauna, determined by Gidley to be of late Pliocene age, has been found. . . . Since the fossils represent a fauna of late Pliocene age and near the top of the formation, deposition of the Gila was completed by the end of Pliocene time, and the uplift is subsequent but not necessarily much later" (Bryan, 1926, p. 169).

Farther north near the Gila River the formation contains interbedded flows of basalt.

Older conglomerates in this same region, such as the Whitetail near Globe (Ransome, 1904a, p. 5), the Pantano near Tucson (C. F. Tolman, unpublished manuscript), and some described by Schrader (1915, p. 54-55) in the Santa Rita and Patagonia Mountains, are believed to be older than the Báucarit and more nearly similar to the conglomerates interbedded in the early Tertiary volcanic rocks of the Sierra Madre. Like them, the older conglomerates of Arizona are more or less intimately related to the volcanic succession.

FIGURE 1. CONGLOMERATE OF UPPER BÁUCARIT
North bank of Río Mayo near Conocárit (Co-ord D-V). Dip is to the west.

FIGURE 2. CONGLOMERATE OF UPPER BÁUCARIT
Lower slope of western *pilar* of Los Pilares (Co-ord D-II)

FIGURE 1. HIGH WESTERN FACE OF SOUTHERN SIERRA DE SAN JAVIER
From Pajarito (Co-ord C-II). Mountains composed of quartzites of Barranca formation, which have been thrust westward over andesitic volcanic rocks (Cretaceous?) that form the lower hills in foreground.

FIGURE 2. HILLS CARVED FROM CONGLOMERATE OF UPPER PART OF BÁUCARIT FORMATION
East side of Río Yaqui east of Toledo (Co-ord C-II)

SIERRA DE SAN JAVIER AND BÁUCARIT FORMATION

MARINE TERTIARY ROCKS

According to Baker (personal communication, 1934), a deep well at Empalme (Co-ord A-IV) penetrated a considerable thickness of marine Tertiary strata. It is possible that marine Tertiary beds overlap from the Gulf of California to the northeastern margin of the coastal plain between Guaymas and the Río Fuerte (Fig. 1). If such strata exist elsewhere than at Empalme, they are now overlain everywhere, so far as known, by the coastal alluvium.

QUATERNARY ROCKS

West of the Sierra de San Javier, the several pediment levels are capped by coarse gravels, which near the mountains or in broad areas of granite may be very thin but thicken to over 30 feet along the main drainage lines. In valleys recently downfaulted, such as that north of Tecoripa (Co-ord C-II), the alluvial fill may attain thicknesses as great as 200 feet. Similarly, fault-block mountains such as the Sierra de Cobachi (Co-ord B-II) are bordered by alluvial fans. There are narrow alluvial fans along the fronts of the faulted ranges farther east, spread out upon the mesas of Báucarit conglomerate. In places along the arroyos and the Río Yaqui narrow strips of fertile flood-plain soils and low-lying alluvial mesas are cultivated.

In a number of areas between Ortiz and Guaymas (Co-ord A-III) recent basaltic flows overlap the eroded faces of fault scarps formed by the older andesitic lavas; some of the original flow surfaces are well preserved (Flores, 1929, p. 241). The basalts south of Ortiz are probably younger than those of the Báucarit formation but for convenience they are shown by the same pattern on the geologic map (Pl. 1). They resemble recent basalt flows in various parts of New Mexico and Arizona.

INTRUSIVE IGNEOUS ROCKS

Coarse-grained intrusive igneous rocks crop out extensively within the area studied. Granites predominate, but diorite and granodiorite are common, principally east of the Río Yaqui. In some of the marginal phases the composition is varied, and locally the intrusives are cut by pegmatite veins and dikes. In places, the Cretaceous and early Tertiary volcanic rocks are cut by many dikes and necks of finer-grained intrusive rocks, some of which may have been the feeders of flows higher up. The most extensive of these are found near Moris (Co-ord E-III), in the Sierra Madre Occidental.

In the Sonoran desert province, the granites are carved to broad pediments and rock plains, at whose margins rise mountains of the older rock. The granites are, in fact, so extensive in this province as to imply

TABLE 8.—*Intrusive igneous rocks of northern Sierra Madre Occidental and adjacent areas*

No.	Locality	Type	Structural relations	Remarks
26.	Cerro San Ignacio-Cerro San Miguel area (Co-ord D-II)	Diorite and quartz diorite. In quartz diorite from near San Miguel, feldspar (orthoclase and plagioclase) makes up about 10% of rock as phenocrysts and is most prominent mineral in groundmass; plagioclase is zoned, ranging in composition from An_{55} in center of crystal to An_{30} at margin; groundmass also contains quartz and various mafic minerals, altered hydrothermally to chlorite and epidote	*See* Figures 4-B, C, D. The diorite apparently extends some distance E under the cover of volcanic rocks, as E of Cerro San Ignacio are some small inliers of contact phase of the plutonic rock	W of Cerro San Ignacio, Palmar limestone is silicified at the contact and impregnated with pyrite and other sulphide minerals. At one place in contact zone, stringers of asbestos occur between the massive, slickensided limestone layers, and in places there are copper-bearing veins. Serpentine, talc, and magnetite occur with asbestos. Early Tertiary rhyolite on E is highly mineralized, particularly along some brecciated zones. W of Cerro San Miguel, Palmar limestone contains veins of galena
25.	SW of Mulatos (Co-ord E-II)	Diorite, having dark, fine-grained peripheral facies	*See* Plate 1, section C-C′	Country rock is mineralized
24.	Moris area (Co-ord E-III & IV)	a) Granite; SW of Sahuayacán has less acid marginal facies; E of Sahuayacán diorite dike intrudes sedimentary rocks	Occurs in two areas along E side Sahuayacán fault zone and one area E of Río Moris fault zone N of Arechuybo. *See* Figure 5-C. W of Arechuybo, limestones E of Río Moris fault seem to be thrust against granite, but Sahuayacán fault seems to be cut off to S by the same granite	
		b) Rhyolite and other dense, light-colored igneous rocks	Occur as narrow dikes and columnar plugs, dome-like masses of oval plan, and great irregular bodies up to 8 square miles in area, which send off elongate dikes into the surrounding andesite and agglomerate. N of Sahuayacán, Sahuayacán fault ends against rhyolite intrusion. *See* Figures 5-B and C and Plate 1, section D-D′	Two plugs rise 500 feet above their surroundings as vertical - sided, rounded pillars, known as El Pilar and Pilar de la Vigia (Bagg, 1905), intruding soft agglomerate, which shows little disturbance in outcrops around their bases
23.	Lluvia de Oro area (Co-ord F-VI & G-V)	Diorite and diabase	Many small intrusions, cutting the volcanic rocks and sedimentary inliers. *See* Figure 5-E	Burrows (1907, p. 665) classifies intrusion at Lluvia de Oro as diabase
22.	Macoribo area (Co-ord F-V)	Granite and diorite	Intrude sedimentary rocks	
21.	Huites area (Co-ord F-VI)	Granite and diorite	Large intrusion into early Tertiary volcanic rocks	
20.	Mesa Caña (Co-ord E-V)	Granite	Intrudes early Tertiary volcanic rocks	Reported by Botsford (1911, p. 705)
19.	Las Guásimas-Los Mezcales (Co-ord E-IV & V)	Diorite	Two areas of diorite intruding early Tertiary volcanic rocks	
18.	Macoyahui - Los Tanques area (Co-ord D & E-V)	Granite, which grades into quartz-free rock in contact zones	Intrudes Cretaceous and Tertiary volcanic rocks and Paleozoic rocks. *See* Plate 1, section E-E′ and Figure 2-E	Eroded to a vast rock plain, above which rise ridges and mountains of andesite and agglomerate which it intrudes; granite on

TABLE 8.—*Intrusive igneous rocks of northern Sierra Madre Occidental and adjacent areas*—Continued

No.	Locality	Type	Structural relations	Remarks
				pediment surface deeply weathered, fresh rock being only in gullies cut 15 feet or more below surface
17.	NE of Tónichi (Co-ord C & D-II)	Granite in greater part, near contacts fine-grained and containing no quartz; along western margin of area contains phenocrysts of feldspar 1 inch across lying in a finer-grained groundmass; toward southern end of mass granite contains large pegmatite dikes; many inclusions of andesite and quartzite occur throughout mass	Large mass extending irregularly at edges into Barranca formation and Cretaceous rocks. *See* Plate 1, sections B-B′ and C-C′. This mass probably more or less connected beneath the surface with smaller areas of plutonic rocks	
16.	S and SW of San Marcos (Co-ord D-II)	Granite, grading locally to granodiorite	Intrudes Barranca and Cretaceous rocks	
15.	E and SE of Toledo (Co-ord C & D-II & D-III)	Near Guamóchil, granites containing many andesite inclusions and cut by large pegmatite dikes	Along contact, surrounding sedimentary and volcanic rocks are much altered	
14.	Río Chico de Ostimuri area (Co-ord C & D-III)	Granodiorite. Specimen of biotite-hornblende granodiorite from El Ojito consists of a holocrystalline aggregate whose grains reach 5 mm. in diameter; zoned plagioclase in subhedral grains makes up about 35% of rock, having composition at center of An_{35} and on rim of An_{25}; quartz in anhedral grains makes up about 30% of rock; microcline in subhedral to anhedral grains makes up 25% of rock; poorly idiomorphic grains of pleochroic biotite and hornblende make up about 5%; as a result of hydrothermal alteration, plagioclase is partly altered to sericite, and biotite and hornblende to epidote and chlorite. Specimen of titaniferous biotite-hornblende granodiorite from 8 miles W of Río Chico de Ostimuri consists of feldspar and quartz in hypidiomorphic grains up to 7 mm. in diameter, comprising 95% of whole; most common mineral plagioclase, which is zoned, with narrow rim whose composition is An_{30} surrounding a core of An_{35}; quartz micrographically intergrown with microcline; biotite and pleochroic hornblende, occurring as scattered spongiform grains, partly replaced by chlorite, epidote, and pyrite; sphene in anhedral grains is prominent constituent, although forming only small percentage of total bulk	Large irregular mass, containing scattered roof pendants of quartzite near Río Chico de Ostimuri. *See* Figure 3-C and D	Surrounding quartzites contain many metalliferous veins, so impregnated with iron they weather to a brilliant red

TABLE 8.—*Intrusive igneous rocks of northern Sierra Madre Occidental and adjacent areas*—Continued

No. Locality	Type	Structural relations	Remarks
13. Sierra de San Javier (Co-ord C-II)	Near San Javier diorite and coarse-grained syenite; diorite at La Barranca; granite W of Potrero de Flores	Various small masses, probably connected at depth. *See* Figure 5-A and Plate 1, section C-C′	Country rocks mineralized near intrusions. *See* Dumble (1900b, p. 13)
12. El Trigo (Co-ord D-IV)	Hornblende granite. Specimen from this locality shows primary minerals to have typical granitic texture, forming a holocrystalline aggregate whose grains reach 5 mm. in diameter; major constituents quartz, microcline, plagioclase (An_{28}), and hornblende; quartz shows strain shadows; microcline contains inconspicuous microperthitic lamellae; both feldspars somewhat altered to sericite; hornblende grains spongiform or skeletal, and intergrown with secondary aggregates of fine biotite flakes, fibrous calcite, and granular epidote	Intrudes Paleozoic limestones and quartzites. *See* Figure 2-D	
11. West of Río Cedros (Co-ord C & D-IV & D-V)	Granite	Occurs in several large areas, in part interconnecting, block-faulted and separated by belts of the volcanic rocks which it intrudes. *See* Plate 1, sections D-D′ and E-E′	In places the intruded rocks strongly mineralized near granite contact
10. Between Sierra de San Javier and Sierra de la Colorada (Co-ord B-I & B & C-II)	Granite, with highly variable composition and grain size; generally coarse-grained and composed of quartz and feldspar, with some biotite; in W part of town of Mazatán granite contains large crystals of muscovite	Intruded into Paleozoic, Barranca, and Cretaceous rocks. *See* Plate 1, section C-C′ and Figure 2-B	Generally eroded to broad pediments, above which rise isolated ridges of sedimentary and volcanic rocks. In Sierra de Mazatán granite forms rugged mountain mass. Intruded rocks generally much altered in contact zone
9. La Colorado mining district (Co-ord A-II)	Oldest intrusion is dike of biotite-augite andesite, cut by diorite, in turn intruded by granite, which is associated with dikes of quartz porphyry; other intrusions cut by dikes of augite andesite; several masses of hornblendite cut metamorphic rocks and diorite	Andesite intrusion local, diorite more extensive, granite widespread, and apparently underlying whole district, the sedimentary and other igneous rocks being overthrust upon it	Information from W. C. Taylor, Jr., of La Colorada
8. Sierra Aconchi and Ures area (Fig. 1)	Granite and derived pegmatites form Sierra Aconchi; granite forms southern continuation Sierra Aconchi at Puerto del Sol; core of next range to E across Río de Sonora also granitic; lesser intrusions of quartz porphyry and related rocks, which are either offshoots of the granite or represent later period of intrusion	E of crest of Sierra Aconchi is area of basic flows and pyroclastics of unknown age; relation of these to granite on W unknown, but intruded by numerous dikes, plugs, and laccoliths of quartz porphyry, some of which are several miles in diameter	Information from R. D. Butler, January 1936. At Puerto del Sol, Río Sonora has cut gorge 2,300 feet deep through granite

TABLE 8.—*Intrusive igneous rocks of northern Sierra Madre Occidental and adjacent areas*—Continued

No. Locality	Type	Structural relations	Remarks
7. Upper basin of Río Sinaloa (Fig. 1)	Granite	Granite of two ages, the older not affecting the overlying andesite, the younger intruding andesite, rhyolite tuff, and breccia of the Tertiary volcanic succession	Described by Hisazumi (1929, p. 103)
6. Río de San Lorenzo, central Sinaloa	Granodiorite	Intrudes limestones of probable Cretaceous age, is overlain unconformably by basal members of the volcanic succession, which contain its reworked fragments	Described by Brown (1925)
5. Guaynopita district (Fig. 1)	Granite	According to Hovey, granite intrusion and accompanying mineralization occurred after deposition of Cretaceous limestone and extrusion of Cretaceous volcanics, but before extrusion of early Tertiary volcanics	Described by Hovey (1907, p. 421-423)
4. El Tigre district (Fig. 1)	Microcline-mica granite	According to Mishler, early Tertiary volcanic rocks lie unconformably on the granite, which intrudes Paleozoic limestones	Described by Mishler (1920, p. 584–585)
3. Nacozari district (Fig. 1)	Granite and monzonite	Granite which intrudes limestone may be pre-Tertiary; also post-volcanic granite and monzonite	Described by Wade and Wandtke (1920, p. 382–383)
2. Sierra Mustefias, SW of Cabullona, (Fig. 1)	Granite	Unconformable below Paleozoic	Described by Taliaferro (1933, p. 18)
1. Cananea district (Fig. 1)	Granodiorite batholith; granite, syenite, and diorite in smaller masses; dikes of various porphyritic intrusive rocks	Intrusions enter both Paleozoic and various formations of extensive volcanic sequence of unknown age, but possibly Cretaceous and early Tertiary	Described by Emmons (1910, p. 319) and Valentine (1936, p. 58). Granites regarded as pre-Cambrian by Emmons; shown by Valentine to be younger

that the whole region is underlain by one vast batholith or a series of related batholiths. Smaller plain areas are found in the northern part of the province of parallel ranges and valleys. A vast plain of granite lies along the Río Mayo east of the valley of the Río Cedros, in the southern part of the province. Farther east, less extensive masses of granite and diorite invade the volcanic rocks of the western or barranca section of the Sierra Madre Ocidental. The principal areas where plutonic igneous rocks are exposed are shown in Pl. 9.

Table 8 describes the localities of intrusive igneous rocks in the area studied and in adjacent regions. Petrographic descriptions of four specimens by Mr. Ward Smith are included.

Aguilera (1896-1897) and Dumble (1900a, p. 151) have assigned large parts of the granite of central Sonora to the pre-Cambrian. Botsford (1911, p. 704) also considered most of the granites in the Álamos district to be of this age although he recognized a younger granite porphyry. Flores (1929, p. 36-41, 111-113, 155-158, 207-209) regarded the granite in central Sonora as partly pre-Cambrian, and partly younger, and perhaps of Mesozoic age. He considered gneissic granite and mica-bearing granite to belong to the older group and granite composed largely of quartz and feldspar to belong to the younger. The writer (King, 1934, p. 95) concluded after completing the first phase of his work that the plutonic rocks were of early Tertiary or late Cretaceous age. He now believes that evidence is lacking that any of the granites are very old, and that basement granites, forming a floor for either the Paleozoic or the Mesozoic sedimentary successions, are not exposed in the region.

Dumble (1900a, p. 146-147) refers to some of the granites as the "granitoid form of the Lista Blanca," the latter being a series of Mesozoic volcanic rocks. It is highly improbable that these surficial igneous rocks ever assume a granitic character, and it is certain that the granites are in no place found at any special stratigraphic position.

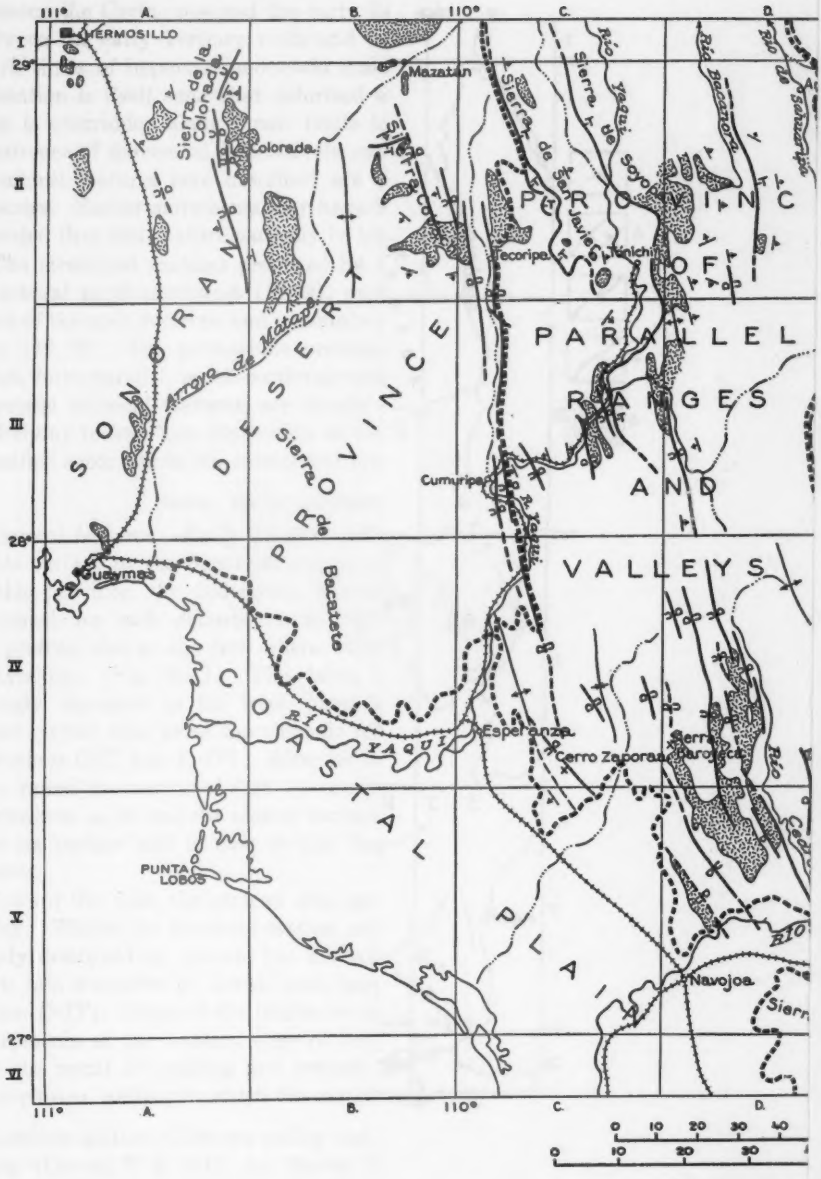
All the granite and other plutonic rocks studied by the writer intrude Paleozoic and Mesozoic rocks and at many places they invade early Tertiary volcanic rocks. There is a possibility that some of the granites are older than the early Tertiary. They are all definitely older than the Báucarit formation, which contains granite fragments, so that the greater part of the intrusions would thus appear to be of middle Tertiary age.

Beyond the limits of the area studied by the writer, plutonic igneous rocks have been described by various authors and assigned to several different ages. These are listed in Table 7. In northern Sonora and southern Arizona, some granites are definitely pre-Cambrian, some were intruded in the late Cretaceous or early Tertiary, and others are younger than the early Tertiary volcanic rocks. In addition, some have been assumed to be either late Paleozoic or late Jurassic (Nevadian), but for the supposedly most typical example, the Sacramento Hill intrusive at Bisbee, considerable contrary evidence has been obtained, which suggests a post-Cretaceous age. This problem has been summarized by Tenney (1932, p. 52-53).

STRUCTURAL GEOLOGY

GENERAL FEATURES

The rocks in the area studied have been much folded and faulted and are intruded by masses of plutonic rocks (Pl. 1). Moreover, there were several periods of deformation. Two of the later unconformities—that

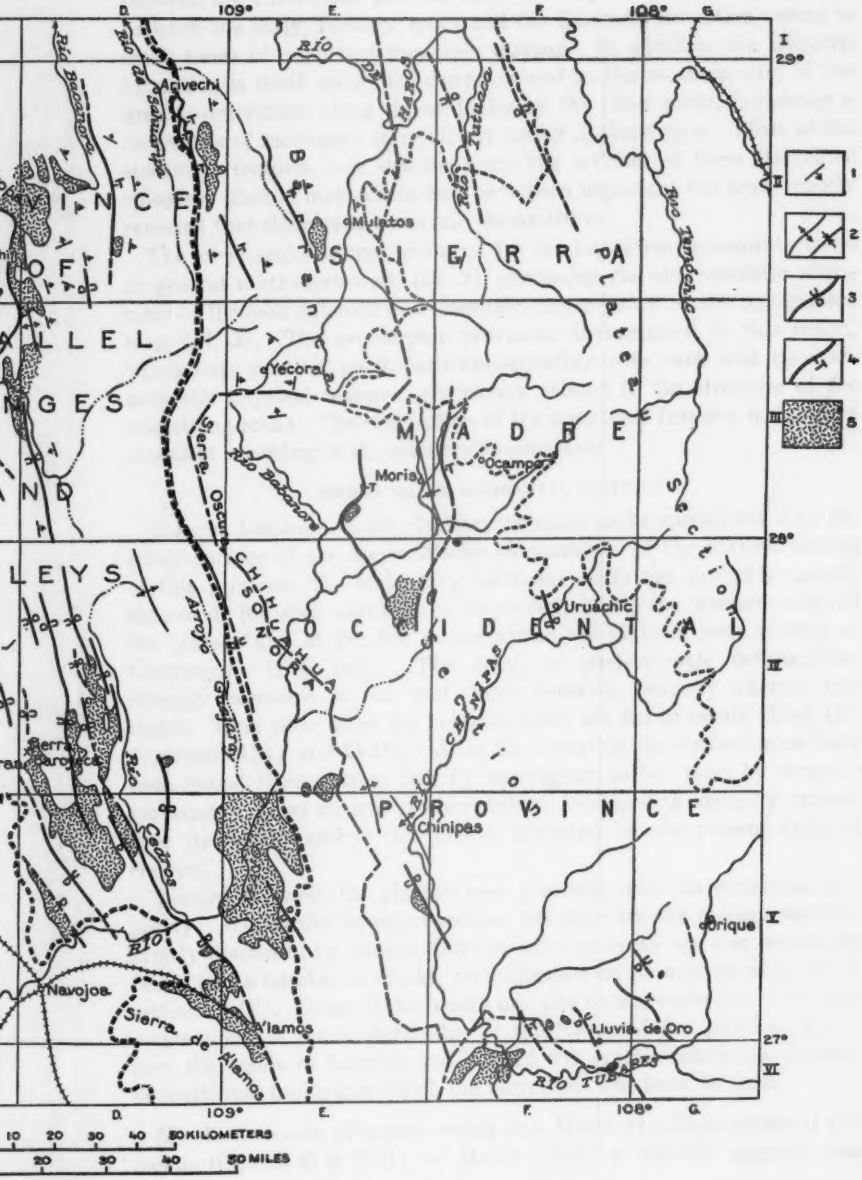


TECTONIC MA

Key to symbols: (1) dip of sedimentary or volcanic rocks; (2) anticlinal and sy
thrown side, indicated by broken line where hypothetical; (4) thrust and overthrust f
plutonic rocks. Boundaries of geomorphic and structural provinces shown by heavy

TECTO

dip of sedimentary or volcanic rocks; (2) anticlina
broken line where hypothetical; (4) thrust and ove
s of geomorphic and structural provinces shown by



TECTONIC MAP

2) anticlinal and synclinal axes; (3) steeply dipping faults, mostly normal, with U on up-
ıst and overthrust faults, with T on overthrust side; and (5) outcrops of granite and other
es shown by heavy dotted lines.

between the Cretaceous and the early Tertiary volcanic rocks and that between the early Tertiary rocks and the Báucarit formation—seem to mark times of important mountain making. In addition, the Báucarit formation is itself somewhat deformed and in the northern part of the area is overridden along thrust faults by the older rocks, indicating a recurrence of movement in relatively recent geologic time. Most of the structural features here described are the product of these last three episodes. Earlier movements may have been important but are so poorly revealed that their nature can only be hinted at.

The structural features produced by the last three movements trend in general north-northwest (Pl. 9), producing the characteristic alignment of the rock outcrops and mountain ridges shown on the topographic map (Pl. 2). The geomorphic provinces distinguished in this report, which form parallel, north-northwest-trending belts, each with its characteristic physical features, are closely related to the structure of the underlying rocks. The description of the structural features is therefore classified according to the geomorphic provinces.

SIERRA MADRE OCCIDENTAL PROVINCE

General features.—Early Tertiary volcanic rocks spread out over the whole surface of the Sierra Madre Occidental. In the plateau section of this province, the underlying Mesozoic rocks are probably greatly deformed, for such disturbance is evident along the western edge of the plateau and at the few inliers within the plateau, such as that at Guaynopita (Fig. 5-A). The later, or post-volcanic deformations strongly expressed to the west, have, however, scarcely affected this region. Over wide areas the volcanic rocks are flat or gently tilted (Pl. 1, sections C-C′ and D-D′). After its formation the surface must have been raised thousands of feet by epeirogenic rather than by orogenic movements, as an ancient erosion surface developed to maturity extends over its surface and is now deeply dissected by the present cycle of erosion.

Toward the west, the plateau area gradually loses its structural simplicity. Within the barranca section, not only are the plateau summits largely destroyed by erosion, but the volcanic rocks are also broken by faults into a number of blocks, each upraised on its western edge (Pl. 1, section D-D′). Some of the blocks are also thrust westward. The high escarpments at the western edge of the Sierra Madre province are in part the result of faulting and toward the north (Sahuaripa district) of overthrust faulting in which the movement was from the east.

Northern section (Tutuaca valley and Mulatos).—Description of this region (Co-ord E & F-II) by Hovey (1907, p. 423-30) suggests that

the easternmost faults probably lie near the Río Tutuaca. East of the northern Tutuaca valley is the high, flat-topped Mesa de Venado, composed of early Tertiary volcanic rocks that dip gently eastward. The mesa rises in a great escarpment 4000 feet above the valley to the west, which is underlain by much dissected "basin sandstone and conglomerate" (Báucarit formation) (Pl. 1), probably downfaulted with respect to the volcanic rocks to the east. The west side of the valley, at the Dolores Mine, is perhaps again upfaulted, as pre-Tertiary schists are encountered there at the same level as a Tertiary basalt flow in the gorge of the Río Tutuaca to the east. The schists are overlain by volcanic rocks which dip southwestward.

To the west, toward Mulatos, the dip reverses, and a long dip slope of lava rises westward to an escarpment which overlooks the valley of Taráchic. The regional east dip is interrupted near Mulatos by a complex local structure. The rhyolites of the district are much shattered and mineralized, and dissimilar lavas lie side by side, presumably by faulting. Whether any major faults cross the district was not determined. East of Mulatos rises the escarpment of the Sierra de Santa Bárbara, composed of volcanic rocks dipping gently toward the east. West of Mulatos the volcanic rocks are invaded by diorite. On the escarpment facing the valley of Taráchic the dip of the volcanic rocks reverses to the west, toward a fault, probably a thrust, along the western base of the escarpment. On the western side of the fault, the Báucarit formation is downthrown against the volcanic rocks and dips eastward at angles of 10 to 20 degrees.

Central section (Moris and Ocampo districts).—Near Ocampo (Co-ord F-III), the volcanic rocks dip gently eastward, and farther east they lie nearly flat. At Ocampo, as shown by Linton (1912, p. 654), they are cut by numerous inclined, northwest-trending fractures, some of which are ore-bearing (Fig. 6-A). At least some of these are normal faults.

Westward, toward Moris (Co-ord E-III), thrust faulting dominates. West of Ocampo the eastward dip of the volcanic rocks increases to 45 degrees, and on the east slope of the valley of the Río Moris the volcanic rocks are underlain by pre-Tertiary limestones and quartzites (Fig. 5-B). Near the river these are thrust westward over andesitic agglomerates of the volcanic succession, along a fault striking nearly north.[8] The agglomerates dip away from the fault at a low angle toward a synclinal axis. West of the Río Moris, near the axis of the syncline, some hills are capped by shattered quartzite and limestone which must be klippen of the fault to the east. The sedimentary rocks occur as large loose blocks

[8] First recorded by J. C. Treadwell (1905, p. 1213), who, however, indicated the dip of the fault as westward rather than eastward.

perhaps as a result of later undercutting of the pyroclastic rocks beneath, which are less resistant to erosion. The Río Moris fault, as it was called by Treadwell, was not traced very far from the crossing of the Ocampo-Moris trail but it apparently is an important line of displacement.

South of Moris, at Arechuybo (Co-ord E-IV), an apparent fault between steeply dipping pre-Tertiary limestones on the east and granite on the west may be the southern extension of the Río Moris fault (Pl. 1). East of Arechuybo, the volcanic rocks dip away from the limestones, with some local reversals.

West of Moris, beyond the synclinal axis, the Tertiary conglomerates and volcanic rocks rise again, and pre-Tertiary sedimentary rocks appear beneath them at Sahuayacán (Fig. 5-C). Between Moris and Sahuayacán, the volcanic rocks are cut by many rhyolite intrusions which have not conspicuously disturbed the surrounding rocks. The sedimentary rocks of the Sahuayacán area, which extend southward across the Río Mayo, are thrust westward over agglomerate and other volcanic rocks, which dip east and northeast at angles up to 30 degrees, along a sinuous fault (Pl. 1). North of Sahuayacán it disappears in and is probably cut off by a large rhyolite intrusion. At its southern end, the fault apparently dies out, but beyond is a large granite mass which may intrude it. In places the argillaceous sedimentary rocks of the overriding block are metamorphosed to schists near the fault plane. In most places they lie directly against the volcanic rocks to the west, but near El Zapote the fault is followed by a long, narrow felsite intrusion. At Agua Caliente de Ramos hot springs rise along fractures associated with the fault.

Southern section (Urique and Lluvia de Oro districts).—South of the Moris district, east of the zone of thrust faults, the plateau was studied between Uruáchic and Urique (Co-ord F&G-IV&V). Here, the volcanic rocks have low dips with general north-northwest strikes. A small fault associated with steeply dipping andesite was observed west of Urique (Pl. 1). Another fault west of Uruáchic, probably a thrust, is downthrown on the east, with andesitic lavas on the upthrown block and soft conglomerate on the downthrown. Small outcrops of metamorphosed limestone at Urique, La Cienaguita, and Piedras Verdes appear to be the summits of buried hills projecting into the volcanic rocks, although there may be some undetermined faults.

Farther southwest near Gloriapán is a large thrust fault, trending southeast (Pl. 1). Northwest of Gloriapán it appears to die out in andesite flows. Southeastward it has been traced 8 miles in a sinuous course to Agua Caliente, where there is no diminution in its throw. Near Gloria-

pán the upthrown side is composed of limestone; farther southeast it is andesite intruded by diorite, part of which is vertical and part dipping toward the fault. The downthrown block consists of soft, reddish conglomerate, dipping at a low angle northeastward toward the fault. Toward

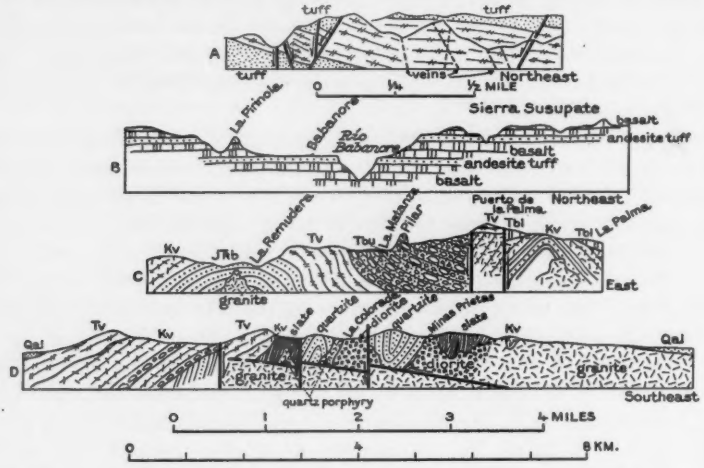


FIGURE 6.—*Sections illustrating the structure of various districts in Chihuahua and Sonora*

(A) Ocampo district, western Chihuahua (Co-ord F-III) (after Linton). (B) Río Babanore, western Chihuahua (Co-ord E-III). (C) Los Pilares area, Sonora (Co-ord D-II). (D) La Colorada district, Sonora (Co-ord A-II) (based on observations of the writer, maps of Flores, and information on underground workings from W. C. Taylor, Jr.). The rocks in Figures A and B are volcanics of early Tertiary age. (JTrb) Barranca formation; (Kv) and (Tv) volcanic rocks of Cretaceous and Tertiary age; (Tbl) lower member of Báucarit formation; (Tbu) upper member of Báucarit formation; (Qal) alluvium.

the southeast, near Agua Caliente, where the throw of the fault appears to be greatest, the andesite on the upthrown side forms a steep, high escarpment, and the conglomerate on the downthrown a broad valley.

The andesite and limestone of Lluvia de Oro, and their extensions northwest and southeast, lie near another line of disturbance. The southernmost point where this belt was studied was at San Francisco del Río on the Río de Tubares. Limestone crops out on the river half a mile below San Francisco and is flanked by andesite. A little farther upstream the andesite is thrust northeast over a diorite intrusive along a fault whose plane dips 35° SW. The limestone inlier at Lluvia de Oro appears to have been a projecting summit of the pre-lava surface, though a vertical fault on the southwest (Fig. 5-E) is mainly responsible for its present height. A rhyolite dike is intruded along the fault line (Burrows, 1907,

p. 665-666). The limestone to the east is broken by a number of minor faults which are roughly parallel to the main fault. Farther northwest another limestone exposure at Bahuérachic may be due to the same causes. The andesites northeast of it are steeply tilted.

Southwest of the limestone at Bahuérachic are other sedimentary rocks, associated in a confusing manner with granite, diorite, and andesite, which end to the west in a high north-northwest-trending ridge. The writer suspects that this complex lies on an overthrust sheet, carried southwest over early Tertiary agglomerates of the Los Molinos valley. In this district there are thus two main lines of displacement (Gloriapán and Los Molinos) toward the southwest. Only the great distance between them and the lack of knowledge of the intervening area discourage one from considering these two fault zones the same as those near Moris. Certainly the faults in the two districts form a part of the same general structural belt (Pl. 9).

Western margin east of valley of Sahuaripa.—In the northern part of the barranca section, west of the downfaulted valley of Taráchic (Co-ord D&E-II), the early Tertiary volcanic rocks rise gently and then steeply westward to the high escarpment that overlooks the valley of Sahuaripa. Cretaceous strata crop out on the escarpment, with a marked angular discordance between them and the overlying volcanic rocks, as shown clearly on the Sierra de las Escobas. It is along this escarpment that the thrust faulting in the area studied is most strikingly and convincingly expressed. The Cretaceous and early Tertiary rocks of the escarpment are clearly overthrust across the late Tertiary Báucarit formation of the valley of Sahuaripa to the west (Fig. 4). The sandstones and conglomerates of the Báucarit formation underlying the valley are little disturbed and dip at angles averaging 15 degrees away from the overthrust at the base of the escarpment.

The overthrust mass consists of two slices. The lower is as much as 1300 feet thick and consists of the Potrero formation, much crumpled and disturbed. This overrides the Báucarit formation and is itself overridden by the upper slice, whose sole is formed by the Palmar limestone. The upper slice overlaps the lower, so that Palmar limestone in places lies directly on the Báucarit formation.

The flatness of the fault planes can be demonstrated clearly at a number of places. Thus, on the northwest side of Cerro de las Conchas, 3 miles east of Arivechi, the limestone of the upper slice projects as a spur into the valley, although below it on its northern side are gently dipping Báucarit conglomerates and sandstones. Also, on the trail up the escarpment from Bámori to San Miguel, thin-bedded sandstones of the Potrero

formation of the lower slice are exposed in a canyon (Fig. 4-C), yet the upper walls of the canyon are composed of steeply dipping Palmar limestones of the upper slice, whose beds, if the fault were absent, should cross the stream channel along the trail.

On the east side of Cerro de las Conchas the anomalous position of certain conglomerates and the relation of the Palmar to the Potrero beds suggest that there may be another fault (Fig. 4-A).

Toward the south along the escarpment the lower slice of Potrero pinches out. The upper slice of Palmar limestone (Fig. 4-D) and the early Tertiary rocks to the east are intruded by a mass of diorite. East of Güisamopa, where the escarpment was crossed farther south, the Cretaceous is absent, and the early Tertiary volcanic rocks lie in fault contact directly against the Báucarit formation to the west.

Some of the movements which raised the scarp may be relatively recent, for the land forms show evidence of uplift. East of the summit of the escarpment are remnants of the high-level mature surface. The summit area is drained by streams flowing through the limestone escarpment to the valley of Sahuaripa, and these have entrenched themselves in deep canyons, presumably as a result of uplift after the mature surface of the uplands had been formed.

Sierra Oscura and Babanore valley.—West of the thrust fault of the Sahuayacán district toward the valley of the Río Babanore, the rocks dip from 10 to 20 degrees eastward toward the fault (Fig. 5-C) (Co-ord D&E-III&IV). A short distance west of the main fault, at Cajón Colorado, 3 miles northwest of Agua Caliente de Ramos, a reddish rhyolite, cut by quartz veins, forms an anticline with steep dips on the west and may be thrust westward on more gently dipping lavas. Farther north, in the high plateau area around Yécora, the volcanic rocks dip gently into a quaquaversal synclinal basin (Pl. 9). On the western side of the Sierra Oscura, where it overlooks the valley of Curupaco, the dip steepens to 10 to 20 degrees eastward, and at the western base of the range the early Tertiary volcanic rocks are upfaulted, perhaps by thrusting, against the low-lying basalts of the Báucarit formation. This fault line is evidently the southern continuation of the overthrust faults on the east side of the valley of Sahuaripa, but the connection was not traced. At any rate, the valley of Curupaco and that of Sahuaripa seem to be a part of the same structural depression.

Chínipas district.—In the vicinity of Chínipas (Co-ord E-IV&V) are several broad anticlinal folds (Pl. 9). Near the town, soft conglomerates and the overlying rhyolites dip at angles up to 35 degrees off the axis of an anticline which trends north-northwest. West of the northern pro-

longation of this fold another anticlinal uplift exposes an extensive area of Cretaceous rocks along its crest and a small diorite intrusion at the axis (Fig. 5-D). A massive limestone layer clearly outlines the major structure. Early Tertiary lavas are unconformable on the Cretaceous, and some of the arching may be pre-Tertiary.

West of these anticlinal folds and southwest of Chínipas a plateau of gently dipping rhyolites breaks off westward in dissected escarpments that overlook the lower country to the west. At Taimuco, pre-Tertiary sedimentary rocks are revealed in a local uplift.

No major fault zone was observed at the edge of the barranca section in this district (Pl. 1, section E-E'). West of Chínipas, the lowlands along the Río Mayo are carved from granite which intrudes the volcanic rocks that rise above it to the east. Farther south, near Los Camotes, the escarpment is flanked on the west by an area of Báucarit conglomerate, containing fragments of volcanic and granitic rocks, and perhaps derived from the erosion of the beds to the east. These rocks appear to overlap the volcanic rocks of the escarpment but are faulted against granite on the southwest. East of Álamos, the escarpment is lower than farther north and apparently was raised chiefly by flexing.

PROVINCE OF PARALLEL RANGES AND VALLEYS

Structurally this province is characterized by a series of mountain ranges bordered by faults. North of the 28th parallel the faults are thrusts and overthrusts. To the south, steep normal faults predominate. Here the uplifts pitch gradually southward, though at a few places there are exceptions to the regional pitch which result in the pre-Báucarit lava flows being raised into high ridges.

West of the valley of Sahuaripa (Co-ord C&D-II&III), the Báucarit basalts rise from beneath the conglomerates and sandstones of the valley at angles of 10 to 20 degrees. Beneath, Cretaceous rocks and early Tertiary volcanic rocks dip more steeply eastward. North of El Encinal these are thrust westward over the Báucarit formation of the Bacanora valley, which dips 10° E. toward the fault. The thrust fault probably dies out south of El Encinal, where the structural height of the range decreases. In this direction the older rocks are overlapped progressively by the Báucarit basalts, which cover it completely south of El Encinal.

West of the valley of Bacanora, the Báucarit basalts rise again to mantle the east flank of the next range to the west. This consists of a complex of much disturbed Paleozoic and early Mesozoic sedimentary rocks and of Cretaceous and early Tertiary volcanic rocks intruded by irregular areas of plutonic rocks. At several places there are steeply dipping homoclines of the stratified rocks, and at others there are anti-

clinal folds. In some districts, however, the structure can only be resolved by more detailed work than has yet been done. Between Los Pilares and La Palma in the southern part of the range, Cretaceous and Tertiary volcanic rocks and the lower and upper Báucarit are confusingly faulted together (Fig. 6-C). Farther south, early Tertiary volcanic rocks extend across the older rocks and near Movas occupy the western part of the range. Báucarit basalt flows cover most of the eastern part of the range in this section.

Between Rebeico and La Dura the various older rocks along the western border of these mountains are faulted against the Báucarit formation of the Yaqui valley. The fault trace strikes generally north, but its course is sinuous, with a re-entrant northeast of Tónichi and a westward-projecting lobe south of La Dura. It has been traced southwest as far as Realito, but its further extension southward is indefinite (Pl. 9). The fault is probably an overthrust to the west. If so, the irregularities in the fault trace may in part be due to erosion of a nearly flat sheet. The isolated occurrence of Barranca quartzite at Toledo may possibly be an outlier of a thrust sheet. At Agua Caliente, east of Tónichi, and three-quarters of a mile east of the fault line, hot sulphur water issues from joints in the granite and may be related to the fault.

The Báucarit beds of the Yaqui valley dip at angles up to 20 degrees in various directions, in many places toward the fault line (Fig. 3-C and D), and near La Dura the fault crosses transversely the strike of the Báucarit beds.

At most places the Báucarit beds and the early Tertiary volcanic rocks rise westward from the Yaqui valley toward the high Sierra de San Javier (Co-ord C-II) with homoclinal dip, but there may be some thrust faulting on the east side of the range. Thus, near San Antonio de la Huerta and some other places, tongues of Barranca quartzite, which forms the greater part of the range, extend out from the main range and are flanked on each side by later volcanic rocks (Pl. 1). The quartzite in the tongues has a homoclinal structure and is best accounted for by faulting.

The western side of the range is a sinuous fault line, which brings Barranca quartzite, standing in a high escarpment (Pl. 8, fig. 1), against Báucarit conglomerate between San Juan de Güiza and Campo Seco, and against Paleozoic rocks of the Casita-Arrastras area between Campo Seco and La Guásima. The Báucarit conglomerate dips at low angles eastward near the fault. The Barranca beds near the fault are so much shattered that all bedding is obliterated, but the higher strata have a fairly gentle dip to the east. Along the road from Güiza to San Javier, the contact between the Barranca and the Báucarit is uneven and undula-

tory, and the quartzite seems clearly to rest on the younger beds. The fault at this place is therefore an overthrust (Fig. 3-A). The relations elsewhere along the mountain front suggest that the quartzite overrides the rocks to the west all along the fault.

Within the Sierra de San Javier, the massive quartzites of the Barranca formation dip generally eastward, but with some great open folds. The lower exposures in some of the deeper canyons are, however, more complicated. In places low-lying exposures of andesite are surrounded by similarly shattered quartzite. These outcrops may represent windows of the thrust sheet. On the other hand, the andesite areas may lie in narrow fault blocks dropped in from above.

South of the Sierra de San Javier, the high quartzite mountains end along an irregular line, and beyond are lower ridges of Cretaceous andesite. This line may mark the south edge of the overthrust sheet, but in part the folded quartzites may pitch in normal succession beneath equally folded younger rocks. The ridges of folded and faulted andesite, interspersed with outcrops of quartzite, granite, and early Tertiary volcanic rocks, extend southward across the segment of the Río Yaqui between Chollas and Cumuripa (Co-ord C-III).

In the Casita-Arrastras Paleozoic area the structure is evidently very complex, with numerous small sharp folds (Fig. 2-A). The Paleozoic strata are overlain locally by patches of lava, probably of lower Báucarit age, and near La Guásima on the Mazatán-Soyopa road they are intruded by granite. They are overlapped toward the south by the Báucarit conglomerate and toward the west by the thick alluvial gravels of the Mazatán valley. The Paleozoic area converges northward with outcrops of the younger lavas and quartzites, and on the southeast with Báucarit conglomerate and Barranca quartzite. Possibly the entire Paleozoic area here is a subsidiary thrust slice carried to the west from the Sierra de San Javier. The evidence obtained is too meager to judge the value of this suggestion.

The ranges in the southern part of the province, east of the Cedros valley (Co-ord D&E-IV&V), are the southern extension of those between the Río de Sahuaripa and the Río Yaqui. They were crossed by the writer in only a few places. Toward the north, between Tezopaco and Curupaco, their whole surface is covered by lower Báucarit basalts, which rise in broad folds to an anticlinal crest near Cuesta de Laurel, the topographic summit (Pl. 1, section D-D′). To the east, they dip toward the synclinal valley of Curupaco at the base of the Sierra Oscura. To the west, there is a general westward dip toward the Cedros valley, although the older volcanic rocks crop out in small inliers and are perhaps in part raised by faulting. Farther south, between El Trigo and

Macoyahui, the older volcanic rocks rise to the surface again and stand in high ridges. The inliers of Paleozoic rocks here may represent the crests of ridges on the pre-lava surface, rather than anticlinal uplifts. To the southeast, along the Río Mayo, the volcanic rocks are intruded by granite, which crops out in an extensive area, its continuity broken only by a few patches of the rocks which it intrudes, which are probably roof pendants.

Along the center of the southern portion of the province (Co-ord D-IV&V, E-V) is a long, narrow belt of downfaulted rocks, which is followed for most of its length by the Río Cedros. The valley is underlain by rocks of the Báucarit formation, most of which dip westward at low angles. To the east, they overlap the early Tertiary volcanic rocks but are locally downfaulted. To the west, along the entire course of the depression, the Báucarit formation is downfaulted against the older rocks. In the Cedros valley section, however, there is a series of en echelon fractures (probably normal faults) (Pl. 9). The only observable dip noted on a fault plane was at the Mina Báucarit, where it was 75 degrees west-southwest, toward the downthrown block.

From the Cedros valley to the coastal plain (Co-ord C&D-IV&V) there are a number of low parallel ranges, separated by depressions, some of which are downfaulted areas, but others, such as the valley of El Volador near the center of the area, the result of downfolding. The ridges are composed in part of Báucarit basalts and conglomerates, which dip at low angles and are in places broadly folded. The Tertiary rhyolites form some of the highest points of the district, both structurally and topographically, and stand in such prominent ranges as Cerro Santa Juliana, Sierra de Baroyeca, Cerro Zaporaa, and Sierra de Álamos. West of Tezopaco there is a slight downwarp in the ranges, which are there structurally low. Toward the south, most of the ranges disappear beneath the alluvium of the coastal plain (Pl. 9), and it is probable that this is due to the southward pitch of the structural features.

SONORAN DESERT PROVINCE

North of lat. 28°30′N. a large proportion of the detached mountain ranges in this province consists of Paleozoic and Mesozoic sedimentary rocks. To the south, in the unmapped area that extends to the coast, they consist of volcanic rocks and granite. The ranges of sedimentary and volcanic rocks appear to be only detached roof pendants in a vast granite batholith or group of coalescing batholiths (Pl. 1, section C-C′). They probably represent the lowest part of the roof at the end of the period of intrusion, the higher parts having been removed by erosion. Nearly all the ranges of nongranitic rock are cut by apophyses of granite.

The granite intrusions have complicated the pre-granite structure of the sedimentary and volcanic rocks by metamorphosing and shattering them close to the contact and by jointing them excessively for some distance from the contact. Alternations of competent and incompetent strata, such as are found in parts of the Paleozoic and the Barranca formation, show such a confusion of dips and small faults that it is very difficult to work out the main structural features. Only the most massive, resistant formations, such as the Permian limestone of Cerro Cobachi (Co-ord B-II) and the upper part of the Barranca formation, show the structure clearly, and even these only at some distance from the nearest granite contact.

Despite these confusing relations, some of the larger features of the structure are plain. The mountains in part are clearly upfaulted. Some (such as those near La Colorada, Co-ord A-II) still preserve the form of tilted fault blocks, although considerably modified by erosion. Some of the depressions are downfaulted, particularly that near Tecoripa (Co-ord C-II), in which the Báucarit formation crops out. Some overthrust faulting is also present in the province, in the vicinity of La Colorada.

The Tecoripa graben (Co-ord B-II, C-II, III&IV), bordered by discontinuous en echelon faults, flanks the western border of the province of parallel ranges and valleys. North of Tecoripa it is filled by alluvium, perhaps as a result of recent subsidence. At and south of Tecoripa gently dipping Báucarit conglomerate forms the floor of the valley, which is bordered by upfaulted granite and volcanic rocks. On each side of the valley at Tecoripa, hot springs rise along the granite-conglomerate contact. To the south, the zone is crossed by the Río Yaqui twice near Cumuripa and once again east of Buena Vista. At Buena Vista only the eastern side of the depression is faulted. Its southern extension lies east of the high rhyolite range of Cerro Zaporaa.

The ranges between the Tecoripa graben and Arroyo de Mátape (Co-ord B-II) culminate in the limestone peak of Cerro Cobachi, which overlooks a granite pediment to the north (Fig. 2-B). In the foothills at the southeast point of the mountain, Dumble (1900a, p. 134) reports that there is

> "a heavy deposit of very granular, light grey, cherty material, having a northwest dip and resting upon a pegmatite granite".

This probably marks a contact between the limestone and a mass of granite. The limestone of the ridge ends along the strike toward the east and west and is probably either cut off by faults or by the granite intrusions. The older Paleozoic rocks to the south may be upfaulted against it, since its dip is toward them.

The Sierra de Cobachi and Sierra de Tecoripa are both bounded by faults on the east and apparently tilted westward toward the valley of the Arroyo de Mátape. West of the Sierra de Cobachi at Cerro Avispa is a low anticlinal fold in the Barranca quartzite and the overlying basalts of lower Báucarit age.

The ranges between Arroyo de Mátape and Llanura de Torres (Co-ord A&B-II) are fault block mountains, tilted in general toward the west. The rhyolite flow which is the highest member of the succession here caps westward-sloping cuestas, varying in size from long, high ranges to small hills within the range, as at Cerro Sombreretillo northeast of Minas Prietas. The lower rocks of the ranges are exposed on the scarps and ridges on their eastern sides. Toward the south they are chiefly quartzites of the Barranca formation (Fig. 3-B) but near La Colorada they are a complex of limestone, quartzite, andesite, and granite.

At La Colorada and Minas Prietas, a striking structural feature is revealed only by mining operations beneath the surface.[9] At depths of 250 to 300 meters (800 to 1000 feet) in all the mine workings, granite is encountered below the quartzite, diorite, and quartz porphyry that contain the mineralized veins (Fig. 6-D). It is separated from the overlying rocks by a plane of shearing, dipping 15° SE., along which there is much brecciation. The granite comes to the surface north and northeast of Minas Prietas, but the fault plane was not recognized as such in the exposure. Granite of the same composition also occurs above the fault plane southeast of Minas Prietas. The direction of movement along the fault plane is not known, although perhaps it was northwest, up the present dip. The overthrust faulting is older than the block faulting of the range, for the thrust plane is displaced by later faults between the Colorada and Crestón mines.

STRUCTURAL GEOLOGY OUTSIDE THE AREA

Very little has been published on the geology of the western Sierra Madre from Álamos south through the State of Sinaloa, and it is not possible to trace in this direction the structural features described in the present report. In Sinaloa, sedimentary rocks crop out in even smaller areas than in southern Sonora. A dominant north-northwest strike is apparent in the topography of parts of the State. Farther south, in the southern part of Sinaloa and in the State of Nayarit, Quaternary volcanic rocks, including the products of recently active volcanoes, conceal most of the underlying rocks.

Imlay (1939, p. 1725) shows that the province of parallel ranges and valleys has the same structural characteristics in northeastern Sonora

[9] Information from Mr. W. C. Taylor, Jr., of La Colorada.

as in the area studied by the writer. Most of the faulting, however, seems to be of normal type. The valley of the Río Bavispe above its junction with the Río Yaqui is apparently the northward continuation of the valley of the Río de Sahuaripa; it extends northward as the San Bernardino valley and enters Arizona east of Douglas. The upper course of the Río de Sonora seems to lie on the northward continuation of the valley which is followed by the Río Yaqui from Soyopa to La Dura. According to Butler (personal communication, 1936), the "Río Sonora in the upper part of its course flows along the trend of a major fault." Butler has worked out an interesting sequence of structural events in a district on the east side of the Sierra Aconchi, west of the Río de Sonora. Here dikes, shear zones, and fissures of nearly east-west trend were traversed by later ore-bearing solutions. These are intersected by later, post-mineral faults of north-south trend, some of which may be older, and some younger than the secondary enrichment of the ore bodies. Probable post-enrichment faulting has brought oxidized ore against primary ore in some places and at others has displaced stream gravels.

In a belt 20 miles in width on the south side of the International Boundary (northeasternmost Sonora and southeastern Arizona), the late Tertiary structures of the province of parallel ranges and valleys crosses an earlier west-northwest structural trend formed in Laramide time (Imlay, 1939, p. 1725; Taliaferro, 1933, p. 35-37). The direction of overfolding and thrusting of the Laramide ranges is dominantly southwestward.

North of the International Boundary, north-northwest trends again prevail. The mountains consist of folded rocks which have in places been overthrust, some to the east and some to the west (Ransome, 1904b; Schrader, 1915, p. 92-96; E. D. Wilson, 1927, p. 31-33; Darton, 1933, p. 183-184; Tenney, 1932, p. 49-51; R. A. Wilson, 1934). The overthrusting seems clearly to be younger than the Upper Cretaceous and in places younger than granite intrusions and Tertiary volcanic rocks. In many places it is older than the normal faults which displace the thrust planes. The Gila conglomerate (correlated with the Báucarit formation of Sonora), which occupies many of the intermontane depressions in the area, is generally considered younger than the overthrusting, although it is reported that in places the formation is somewhat deformed. The part played by overthrusting in outlining the present mountain ranges is not known.

SUMMARY OF STRUCTURAL HISTORY

Paleozoic era.—During the Paleozoic era, Sonora was the scene of widespread but discontinuous deposition, chiefly of limestone, to an unde-

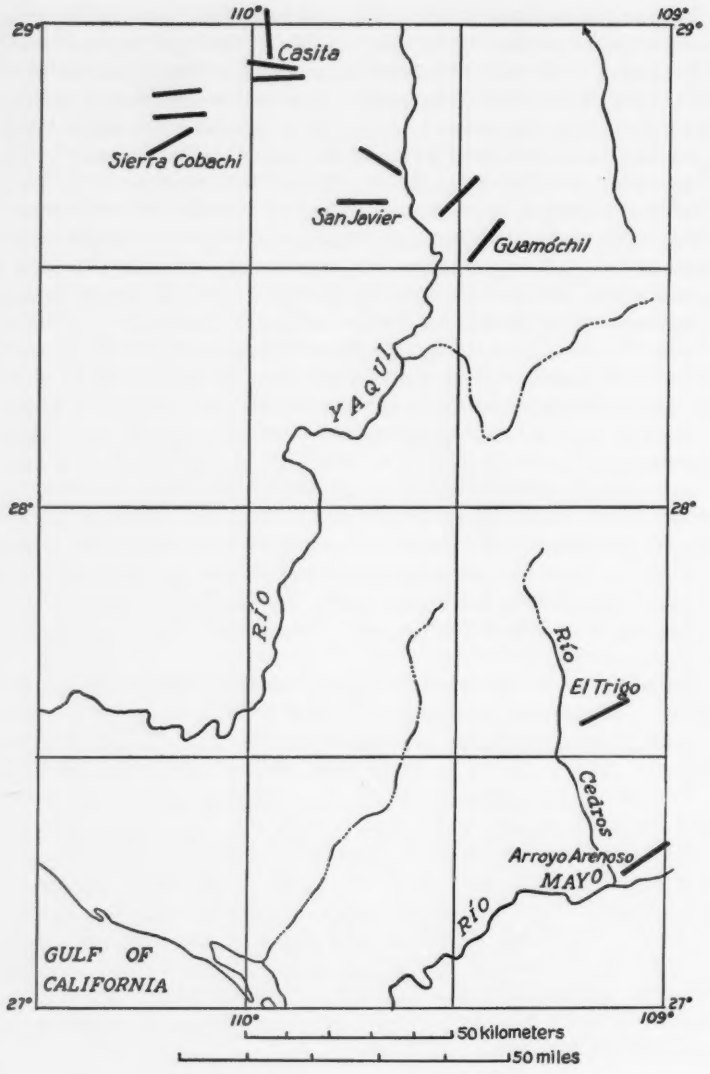


FIGURE 7.—*Structure of Paleozoic rocks*

Known directions of strike of Paleozoic rocks shown by heavy lines. Illustrates the discordance of these strikes to the north-northwest trend of the later structural features.

termined thickness. In central Sonora, within the area of this report, rocks of Ordovician and Permian age are indicated by fossils, but whether the intervening systems exist is not known. Farther north, along the northern edge of the State of Sonora, Devonian, Mississippian, and a thick sequence of Pennsylvanian rocks intervene between the older Paleozoic and the Permian. The outlines of the Paleozoic basins of deposition are not established. Possibly the basins did not extend southward beyond the southeastern corner of the State, since few Paleozoic rocks are known in that section, and they are not reported beyond. They may, however, have been completely buried by the younger rocks or engulfed in much younger granite intrusions. Eastward, the Permian rocks certainly extended as far as the Sahuaripa district, since fossils of that age occur in boulders in the Cretaceous conglomerates there.

The deformations to which these rocks were subjected in Paleozoic time are also poorly known. Perhaps the older Paleozoic rocks were deformed before the deposition of the Permian. Observations by Dumble (1900a, p. 135, 151) suggest that there is an unconformity between the rocks of the two ages on Cerro Cobachi, but the writer has not been able to confirm this relation. Pre-Permian Paleozoic movements are important in trans-Pecos Texas farther northeast.

Post-Permian and pre-Upper Triassic movements may have been important. In central Sonora, the Permian strata seem generally to be somewhat more deformed and metamorphosed than the overlying strata. Moreover, a plotting of the observed strikes of the Paleozoic rocks of the area shows them to be in a general eastward direction, or transverse to the trend of the present structural features (Fig. 7). In southern Arizona and New Mexico, post-Permian movements older than the Cretaceous are indicated in numerous places by the overlap of the basal Cretaceous across the Paleozoic and even upon the pre-Cambrian rocks. The best known example is in the Bisbee district, where faulting took place and a rugged surface was developed before deposition of the Cretaceous, but a granite intrusion formerly considered to be older than the basal Mesozoic conglomerate may actually be younger.

Mesozoic era.—During early Mesozoic time (Rhaetic and Lias) a part of Sonora was covered by the thick Barranca clastic rocks. The eastern margin of the basin in which they were deposited evidently extended southeastward from northeastern Sonora across western Chihuahua. Toward the eastern side, the strata are wholly of continental origin. Marine fossiliferous horizons are intercalated toward the west. The Barranca basin may have been connected northwestward with the geosynclinal basins which received thick early Mesozoic deposits in the Coast

Ranges and Sierra Nevada of California, and with the Upper Triassic and Lower Jurassic basin of west-central Nevada. Toward the southeast it was probably linked with the early Mesozoic geosyncline of central and southern Mexico.

The question of the extent in Arizona and Sonora of middle Mesozoic (Nevadian) deformation and intrusion has been much discussed. Tenney (1930, p. 275-277) has suggested that the basin of early Mesozoic deposition in the Altar district of northwestern Sonora, and the country to the north of it, were folded into mountain ranges before Cretaceous time, but that, in southwestern Arizona, erosion has carried away all but the pre-Cambrian roots of the former mountain chains. A geosyncline certainly existed in this area, but no strong unconformity between the earlier and later Mesozoic rocks has been discovered, and the field relations in central Sonora seem rather against such movement. The observed unconformities, such as that near Bisbee, might as easily be late Paleozoic.

Cretaceous seas seemingly advanced from the southwest in Neocomian time. In the Albian limestone deposits apparently extended westward from the main area of deposition in Texas and eastern Mexico as far as southeastern Arizona and the Sahuaripa district. The limestones are associated with and pass both laterally and upward into clastic rocks, which at Sahuaripa are interbedded with volcanic rocks. Recurrent uplift accompanied by volcanic activity occurred on the margins of the basin. The extensive volcanic rocks west of Sahuaripa in Sonora apparently were erupted during this Lower Cretaceous volcanism.

At the northern edge of Sonora in the Cabullona district, Taliaferro (1933, p. 32) has found evidence of considerable disturbance between Lower and Upper Cretaceous time, but such movements have not been recorded elsewhere, and their extent is not known. An unconformity between the Lower and Upper Cretaceous may account for the thick development of the Lower Cretaceous at some places in this region and its apparent absence at near-by localities, where Upper Cretaceous beds overlap still older rocks.

Upper Cretaceous deposition was extensive in southeastern Arizona and southern New Mexico and was accompanied, toward its close, by volcanism—the second epoch in Cretaceous time. Upper Cretaceous rocks have not been identified south of northernmost Sonora, and it is not known how far southward the sediments and associated volcanic rocks of this series were laid down.

Diastrophism in Sonora at the close of Cretaceous time was a part of a general movement which disturbed the country farther east in Mexico, as well as much of the southwestern United States. The Cretaceous rocks are markedly unconformable beneath and considerably more folded than

the Tertiary volcanic rocks which overlie them. Some of the granites of central Sonora were probably intruded at this time, although none of this age have been proved. Late Cretaceous or early Tertiary granites are known at various places in the southwestern United States, in northern Sonora and Chihuahua at El Tigre, Nacozari, and Guaynopita, and in Sinaloa. After the post-Cretaceous movements, the region was considerably eroded and in places was carved into rugged topography, as is suggested by the relations at Guaynopita, Lluvia de Oro, and elsewhere within the Sierra Madre Occidental province.

Tertiary period.—The volcanic eruptions which followed the mountain making of early Tertiary time reached their greatest development in the plateau section of the eastern Sierra Madre Occidental. Here, a great thickness of flows and associated pyroclastic rocks were spread out, but to the west the accumulation was thinner.

After the early Tertiary eruptions, there was further mountain making. Within the plateau section of the Sierra Madre the volcanic rocks were only gently folded and over wide areas they still remain nearly horizontal. This gentle folding contrasts with the strong disturbance of the Cretaceous and other Mesozoic rocks where they can be observed beneath, which indicates that here the post-Cretaceous—pre-volcanic disturbance was the greatest. Farther west, as in the province of parallel ranges and valleys, the mid-Tertiary deformation apparently equals or exceeds the earlier, post-Cretaceous movement, and it was probably at this time that the mountains began to assume their present form. At any rate, the early Tertiary volcanic rocks are generally unconformable below the later Tertiary Báucarit formation, and that formation seems to have been deposited in intermontane basins which had nearly the same positions and outlines as the present longitudinal valleys.

Accompanying this middle Tertiary movement, there were vast intrusions of granite and other plutonic rocks, which ascended through the Paleozoic and Mesozoic rocks and in places penetrated the early Tertiary volcanic rocks. Some of the faulting may have been initiated at this time. Several of the thrust faults which break the early Tertiary volcanic rocks of the barranca section are cut off by granite intrusions.

During and after the middle Tertiary movements, the late Tertiary Báucarit formation was laid down in the structural depressions between the uplifted mountain ranges. A moderate recurrence of volcanic activity is indicated by the basalt flows in the lower part of the formation. Interbedded with and overlying the basalts are conglomerates which were doubtless laid down on coalescing alluvial fans at the margins of the

mountains. They contain fragments derived from the erosion of the cores of the ranges, including boulders of granite.

At the close of Báucarit time, there was renewed orogenic activity, probably along pre-existing lines of folding and faulting. The Báucarit formation was tilted and thrown into low folds. North of the 28th parallel the rocks of each of the high mountain ranges, from the crest of the Sierra Madre westward into central Sonora, were pushed to the west on overthrust faults, which partly overrode the Báucarit formation lying in the valleys next to the west. Some minor faults were thrust to the east. The strong thrusting and the gentle warping of this orogenic epoch suggest that the strata of the mountains had already become so consolidated by previous folding and igneous intrusions that they could no longer yield to lateral pressure by folding. The greater amount of thrusting north of the 28th parallel may be due to the greater thickness of Paleozoic and Mesozoic sedimentary rocks in that region.

The normal faults extensively developed south of the 28th parallel and farther west in central Sonora were somehow related to the thrust faults. At La Colorada (Co-ord A-II) these offset the plane of an overthrust fault, but both here and to the south they have the same north-northwest trends as the overthrusts and thus may have taken their form from the same forces. In the province of parallel ranges and valleys, the localization of overthrusts north of the 28th parellel and of normal faults to the south of it suggests that the orogenic forces, although dominantly compressional, produced local areas of tension.

During rather recent geologic time, a mature erosion surface of low relief was developed in the lava country along the crest of the Sierra Madre. After its formation, the area was greatly uplifted, and streams draining to the west deeply intrenched their courses, forming the tremendous barrancas of the western flank of the Sierra Madre. It is not entirely certain when this uplift took place, but the great height of the surface above low country not far to the west strongly suggests that it was raised by faulting on the west side of the plateau. This faulting may have been the post-Báucarit thrust faulting or it may have been a renewed movement at a later time along the same trends.

The rivers draining southwestward from the Sierra Madre to the Gulf of California probably took their present form after this uplift. The preceding Báucarit formation seems to have been laid down largely in inclosed basins, and through-flowing drainage probably did not exist at that time. With renewed uplift, the rainfall of the highlands was no doubt greatly increased, causing much water to shed off westward. Such waters found their way to the sea by overflowing the low points in the pre-existing topography, and the rivers thus established superimposed

themselves on the structural features of the underlying bedrock. A similar history has been suggested by Blackwelder (1934) for the Colorado River farther north.

During the Tertiary period, while these events were taking place in the Sierra Madre Occidental, the Sierra Madre Oriental on the eastern side of the Mexican Mesa Central was also being deformed. Here, thick Mesozoic sedimentary rocks had been deposited and during several epochs in the Tertiary these were thrown into long parallel folds and were overthrust toward the east. Plutonic rocks were not extensively intruded in this region.

There were, therefore, fundamental differences in the character of the deformation on the west and east sides of the Mesa Central. The eastern sierra, in which sedimentation dominated, was folded and overthrust to the east, with very little igneous activity. The western sierra, a center of volcanic activity, was intruded by great masses of igneous rocks and broken into slices which were overthrust toward the west.

Quaternary period.—Since post-Báucarit orogeny, the region has been relatively stable, and the streams have cut deeply into the mountain ranges and plateaus. Some recurrence of movement is suggested, however, by the recent emergence of parts of the coastal area from the Gulf of California and by the earthquake of 1887, which affected the northern part of the region.

ECONOMIC NOTES

Within the area studied, the chief mineral resources are gold, silver, and copper. These are widely distributed, and some of the deposits are very rich, so that since Spanish colonial days there has been prospecting and development of mines. Many mines were visited during the present investigation. The purpose of this study was chiefly to work out the general geology and the geologic history, and the observations made on the mines are necessarily incomplete. The following notes give some general information on the occurrence of the ores.

All the mineralization in the region is definitely older than the Báucarit formation. The deposits also appear to be older than the overthrust faulting. Thus, at La Colorada (Co-ord A-II) the rich gold-bearing veins terminate downward at the overthrust fault and have never been found in the granite on the other side (Fig. 6-D).

The mineralization is closely related to the intrusions of granite and other plutonic rocks, and many of the ore bodies lie near the peripheries of such bodies. Since there may have been several intrusions of granite, there may also have been several times of mineralization. However, since most of the granites seem to have been intruded in the middle

Tertiary, this would also seem to have been the chief time of mineralization. There is a possible relation between ore concentration and the degree of differentiation of the intrusive plutonic rocks. At La Colorada the composition of the intrusive rocks varies widely, whereas in the barren surrounding areas granites prevail.

In the Sierra Madre Occidental province, ore deposits occur in both the Tertiary volcanic rocks and the inliers of pre-Tertiary sedimentary rocks. The ores in the Tertiary volcanic rocks occur in veins or groups of veins (as at Ocampo and Pinos Altos, Co-ord F-III, Fig. 6-A), or in brecciated areas (as at Mulatos, Co-ord E-II). Some of these are close to igneous intrusions. The large intrusions of rhyolite near Moris and Sahuayacán (Co-ord E-III) seem to have been responsible for most of the mineralization in that district (Fig. 5-C). At Ocampo the ore deposits are far from any exposed intrusions, but they may lie above one that has not been uncovered by erosion. The occurrence of ores in the pre-Tertiary sedimentary rocks may be related to the thrust faults which bring them to the surface. Though the thrusts are younger than the mineralization, lines of weakness may have existed previously which aided in the ascent of the ore-bearing solutions. They may also be a product of pre-volcanic mineralization; such a relation was assumed by Hovey at Guaynopita (Fig. 5-A).

Farther west, in the province of parallel ranges and valleys, the chief ore deposits occur as veins in the areas of uplifted older rocks, in the forward parts of the thrust sheets; they are generally in the vicinity of granite intrusions. The San Javier silver mines (Co-ord C-II) produce from veins in the Barranca quartzite, and the Mina Baroyeca (Co-ord C-IV) from fractured, silicified Tertiary andesite. The Mina Báucarit (Co-ord D-V) is in veins in granite, close to a fault which drops down Tertiary volcanic rocks to the west. The veins are parallel to the fault, and some mineralization occurs along the fault itself, so that the ore body may be post-normal faulting.

Placer gold occurs at a number of places in arroyos and in the gravel terraces bordering the Río Yaqui. During 1932 and 1933, when other mining operations were suspended, many men were making their living by washing gold. Rich streaks and pockets exist in the deposits, but the average value per ton is probably too low to justify large-scale operations.

In the vicinity of San Javier (Co-ord C-II), coal has been extensively mined from the Barranca formation, chiefly for local use at the mines of San Javier (Fig. 3-A). In places it approaches an anthracite and has about 86 per cent fixed carbon. Near some igneous intrusions it is altered to a natural coke.

East of Ónavas (Co-ord C-III) and in the Sierra de Moradillas northwest of San Marcial (Co-ord B-II) (Fig. 3-B), the coal beds have been still further altered to graphite, which has a good quality at many places. The graphite deposits of the Santa María mine at El Lápiz Viejo, in the northern Sierra de Moradillas, have been described by Hess (1909). Information on other mines is given by Flores (1929, p. 125-129). Additional notes have been published by Newberry (1887). The graphite occurs in steeply tilted, quartzitic, and in part pebbly sandstones containing crystals of andalusite. There are at least seven beds, mostly less than three feet thick, although one layer averages 9 feet thick, being in part thickened by tectonic squeezing. Flores (1929, p. 115) suggests that intrusions of hornblende andesite metamorphosed Barranca coals to produce the graphite, whereas Hess believes that metamorphism due to intrusions of granite, since there are dikes and stringers of granite in the Santa María deposit. To the writer, the latter suggestion is more probable. He interprets the andesite as extrusive. Moreover, granite intrusions occur near all graphite deposits of the region, while the andesite is only locally developed in association with them.

BIBLIOGRAPHY

All articles referred to in the paper and most of the publications of interest on the geology of Sonora are here listed. Some papers on related subjects in adjoining regions are also included. Articles not otherwise designated deal with Sonora and adjacent parts of Chihuahua. Articles followed by (Mex.) deal either with near-by areas in Mexico or with Mexico in general. Articles followed by (U. S.) deal with near-by areas in the United States, and particularly with southern Arizona.

Aguilera, J. G. (1896-1897) *Bosquejo geológico de México,* Inst. Geol. México, Bol., vols. 4-6 (Mex.) (Information on Sonora is given at various scattered places in the text.)

Angermann, Ernesto (1904) *Apuntes sobre el Paleozoico en Sonora,* Inst. Geol. México, Parergones, vol. 1, p. 81-90.

Bagg, R. M. (1905) *The Sahuayacán district, Mexico,* Eng. Min. Jour., vol. 79, p. 749-751.

Blackwelder, Eliot (1934) *Origin of the Colorado River,* Geol. Soc. Am., Bull., vol. 45, p. 551-566 (U. S.).

Botsford, C. W. (1911) *Southern Sonora and Chihuahua,* Eng. Min. Jour., vol. 92, p. 704-706.

Brand, Donald D. (1937) *The natural landscape of northwestern Chihuahua,* Univ. New Mex. Bull., Geol. ser., vol. 5, no. 2.

Brown, W. H. (1925) *Geological section along Río de San Lorenzo, Sinaloa,* Eng. Min. Jour., vol. 120, p. 691 (Mex.).

Bryan, Kirk (1926) *San Pedro valley, Arizona, and the geographic cycle* [Abstract], Geol. Soc. Am., Bull., vol. 37, p. 169-170 (U. S.).

Burckhardt, Carlos (1923) *Quelques remarques critiques sur l'ouvrage de M. W. Fruedenberg "Geologie von Mexico",* Mem. Soc. Antonio Alzate, vol. 41, p. 185 (Mex.). (Discovery of Triassic ammonoids in Sonora.)

Burckhardt, Carlos (1930) *Étude synthétique sur le Mésozoïque mexicain*, Soc. Paléont. Suisse, Mém., vols. 45-50 (Mex.).

Burrows, R. H. (1907) *The Lluvia de Oro district, Mexico*, Min. Sci. Press, vol. 94, p. 664-667.

——— (1908) *Sobre rhynchonellas y belemnitas del Jurásico en Lluvia de Oro, Chihuahua*, Soc. Geol. México, Bol., vol. 4, p. 15-16.

Campbell, M. R. (1903) *The Deer Creek coal field, Arizona*, U. S. Geol. Survey, Bull 225, p. 245-247 (U. S.).

Cotteau, G. H. (1890) *Note sur quelques echinides du terrain cretace du Mexique*, Soc. Geol. France, Bol., 3d ser., vol. 18, p. 292-299 (Mex.).

Darton, N. H. (1925) *Résumé of Arizona geology*, Univ. Ariz. Bull. 119 (U. S.).

——— (1933) *Guidebook of the western United States, Part F, Southern Pacific Lines*, U. S. Geol. Survey, Bull. 845 (U. S.).

Dumble, E. T. (1900a) *Notes on the geology of Sonora, Mexico*, Am. Inst. Min. Eng., Tr., vol. 29, p. 122-152.

——— (1900b) *Triassic coal and coke in Sonora*, Geol. Soc. Am., Bull., vol. 11, p. 10-14.

——— (1901a) *Cretaceous of Obispo Canyon, Sonora*, Tex. Acad. Sci., Tr., vol. 4, p. 81.

——— (1901b) *Occurrence of oyster shells in volcanic deposits in Sonora, Mexico*, Tex. Acad. Sci., Tr., vol. 4, p. 82.

——— (1902) *Notes on the geology of southeastern Arizona*, Am. Inst. Min. Eng., Tr., vol. 31, p. 696-715 (U. S.).

Emmons, S. F. (1906) *Los Pilares mine, Nacozari, Mexico*, Econ. Geol., vol. 1, p. 629-643.

——— (1910) *Cananea mining district of Sonora, Mexico*, Econ. Geol., vol. 5, p. 312-356.

Flores, Teodoro (1929) *Reconocimientos geológicos en la región central del estado de Sonora*, Instit. Geol. México, Bol., no. 49.

Gabb, W. M. (1864) *Description of the Triassic fossils in California and adjacent territories*, Paleont. Calif., vol. 1, Calif. Geol. Survey, p. 28. (Description of a Triassic fossil from Sonora.)

——— (1869) *Notes on some Mexican Cretaceous fossils, with descriptions of new species*, Paleont. Calif., vol. 2, Calif. Geol. Survey, p. 257-276. (Description of Arivechi fauna.)

Hess, F. L. (1909) *Graphite mining near La Colorado, Sonora*, Eng. Mag., vol. 28, p. 26-48.

Hisazumi, Hisakichi (1929) *Informe geológico preliminar de la parte norte del estado de Sinaloa*, Instit. Geol. México, Anales, vol. 3, p. 95-109 (Mex.).

Hovey, E. O. (1906) *The geology of the Guaynopita district, Chihuahua*, Festschrift Harry Rosenbusch, p. 77-95, Stuttgart.

——— (1907) *A geological reconnaissance in the western Sierra Madre of the state of Chihuahua, Mexico*, Am. Mus. Nat. Hist., Bull., vol. 23, p. 401-442.

Humphreys, E. W. (1916) *Triassic plants from Sonora, Mexico, including a Neocalamites not previously reported from North America*, N. Y. Bot. Garden, Mem., vol. 6, p. 75-78.

Hynes, D. P. (1912) *Notes on the geology of the Mina Mexico vein*, Econ. Geol., vol. 7, p. 280-286.

Imlay, R. W. (1938) *Studies of the Mexican geosyncline*, Geol. Soc. Am., Bull., vol. 49, p. 1651-1694 (Mex.).

Imlay, R. W. (1939) *Paleogeographic studies in northeastern Sonora,* Geol. Soc. Am., Bull., vol. 50, p. 1723-1744.

Jaworski, E. (1929) *Eine Liasfauna aus nordwest Mexico,* Schweizer Paleont. Gesell. Abh., vol. 48, part 4, p. 1-12.

Keller, W. T. (1928) *Stratigraphische Beobachtungen in Sonora, n. w. Mexico,* Soc. Helvétique Sci. Nat. Actes, 109th sess., p. 170-172; Ecl. Geol. Helvétique, vol. 21, p. 327-335.

Kellum, L. B. (1936) *Evolution of the Coahuila peninsula, Mexico. Part III. Geology of the mountains west of the Laguna District,* Geol. Soc. Am., Bull., vol. 47, p. 1039-1090 (Mex.).

King, R. E. (1934) *Geological reconnaissance in central Sonora,* Am. Jour. Sci., 5th ser., vol. 28, p. 81-101.

Lasky, Samuel G. (1938) *Newly discovered section of Trinity age in southwestern New Mexico,* Am. Assoc. Petrol. Geol., Bull., vol. 22, p. 524-540 (U. S.).

Linton, Robert (1912) *Geology of the Ocampo district, Mexico,* Eng. Min. Jour., vol. 94, p. 653-658.

McGee, W J (1896) *Expedition to Seriland,* Science, n. s., vol. 3, p. 493-505.

——— (1897) *Sheetflood erosion,* Geol. Soc. Am., Bull., vol. 8, p. 87-112.

———, and Johnson, W. D. (1896) *Seriland,* Nat. Geogr. Mag., vol. 7, p. 125-133.

Merrill, F. J. H. (1908a) *Mineral resources of Sonora,* Min. Sci. Press, vol. 96, p. 33-40.

——— (1908b) *Metamorphic ranges in Sonora,* Min. Sci. Press, vol. 97, p. 296.

Mishler, R. T. (1920) *Geology of the El Tigre district, Sonora,* Min. Sci. Press, vol. 121, p. 583-591.

Mitchell, G. J. (1928) *The geology of Sonora,* Science, n. s., vol. 67, p. 373. (Discovery of Carboniferous fossils at Cananea.)

Muller, S. W., and Ferguson, H. G. (1936) *Triassic and Lower Jurassic formations of west central Nevada,* Geol. Soc. Am., Bull., vol. 47, p. 241-252 (U. S.).

Newberry, J. S. (1876) *Geological report,* in *Report of exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the west, in 1859, under Capt. J. N. Macomb,* U. S. Army, Dept. Engin., p. 141-148. (Description of Triassic plants from Sonora.)

——— (1887) *The origin of graphite,* School Mines Quart., vol. 8, p. 334-335.

Paige, Sidney (1916) *Silver City folio,* U. S. Geol. Survey, Geol. Atlas, no. 199 (U. S.).

Ransome, F. L. (1904a) *Globe folio,* U. S. Geol. Survey, Geol. Atlas, no. 111 (U. S.).

——— (1904b) *Bisbee folio,* U. S. Geol. Survey, Geol. Atlas, no. 112 (U. S.).

——— (1923) *Ray folio,* U. S. Geol. Survey, Geol. Atlas, no. 217 (U. S.).

Rémond, Auguste (1866) *Notice of geological explorations in northern Mexico,* Calif. Acad. Sci., Pr., vol. 3, p. 244-257.

Ross, C. P. (1925a) *Geology and ore deposits of the Aravaipa and Stanley mining districts, Arizona,* U. S. Geol. Survey, Bull. 763 (U. S.).

——— (1925b) *Ore deposits of the Saddle Mountain and Banner mining districts, Arizona,* U. S. Geol. Survey, Bull. 771 (U. S.).

Santillán, Manuel (1936) *Synopsis of the geology of Mexico,* Am. Assoc. Petrol. Geol., Bull., vol. 20, p. 394-402 (Mex.).

Schrader, F. C. (1915) *Mineral resources of the Santa Rita and Patagonia Mountains, Arizona,* U. S. Geol. Survey, Bull. 582 (U. S.).

Schuchert, Charles (1923) *Sites and nature of the North American geosynclines,* Geol. Soc. Am., Bull., vol. 34, p. 151-221 (U. S., Mex.).

——— (1935) *Historical geology of the Antillean-Caribbean region,* John Wiley & Sons, New York (Mex.).

Self, E. D. (1894) *A visit to the falls of Basaseáchic,* N. Y. Acad. Sci., Tr., vol. 13, p. 148-151.

Stoyanow, A. A. (1936a) *Correlation of Arizona Paleozoic formations,* Geol. Soc. Am., Bull., vol. 47, p. 459-540 (U. S.).

——— (1936b) *Occurrence of the Malone and Torcer faunas at the base of the Arizona Comanchean,* Science, n. s., vol. 83, p. 328 (U. S.).

——— (1936c) *Jurassic and early Cretacic faunas from Arizona* [Abstract], Pan-Am. Geol., vol. 65, p. 375-376 (U. S.).

——— (1937) *Fossiliferous zones in the Cretaceous and Tertiary deposits of southeastern Arizona* [Abstract], Geol. Soc. Am., Pr. 1936, p. 296-297 (U. S.).

——— (1938) *Lower Cretaceous stratigraphy in southeastern Arizona* [Abstract], Geol. Soc. Am., Pr. 1937, p. 117 (U. S.).

Taliaferro, N. L. (1933) *An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico,* Jour. Geol., vol. 41, p. 12-37.

Tays, E. A. H. (1910) *The Lluvia de Oro mine,* Min. Sci. Press, vol. 100, p. 59-60.

Tenney, J. B. (1930) *Discussion of relations of ore deposits of the southern Rocky Mountain region to the Colorado Plateau,* Colo. Sci. Soc., Pr., vol. 12, p. 269-277 (U. S.).

——— (1932) *The Bisbee mining district,* in *Ore deposits of the southwest,* 16th Intern. Geol. Congr., Guidebook 14, p. 40-67 (U. S.).

Treadwell, J. C. (1905) *The Sahuayacán district, Mexico,* Eng. Min. Jour., vol. 80, p. 1213-1216.

Valentine, W. G. (1936) *Geology of the Cananea Mountains, Sonora, Mexico,* Geol. Soc. Am., Bull., vol. 47, p. 53-86.

Wade, W. R., and Wandtke, Alfred (1920) *Geology and mining methods at Pilares Mine, Sonora, Mexico,* Am. Inst. Min. Eng., Tr., vol. 63, p. 382-407.

Weed, W. H. (1902) *Notes on certain mines in the states of Chihuahua, Sinaloa, and Sonora, Mexico,* Am. Inst. Min. Eng., Tr., vol. 32, p. 396-443 (Mex.).

Wieland, G. R. (1926) *The El Consuelo cycadeoids,* Bot. Gazette, vol. 81, p. 72-86 (Mex.).

Wilson, E. D. (1927) *Geology and ore deposits of the Courtland-Gleeson region,* Univ. Ariz. Bull. 123 (U. S.).

Wilson, R. A. (1934) *Thrust faulting in the Empire Mountains of southeastern Arizona,* Jour. Geol., vol. 42, p. 422-429 (U. S.).

Anonymous (1924) *Informe sobre la exploración de los distritos de Altar, Hermosillo, Guaymas, y Álamos, del estado de Sonora, México, por la Compañía Petrolera de Sonora, S. A.,* Bol. de Petroleo, vol. 17.

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PALEOGEOGRAPHIC STUDIES IN NORTHEASTERN SONORA

BY RALPH W. IMLAY

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ABSTRACT

Thick Upper Paleozoic offshore limestones and Cretaceous near-shore deposits in northeastern Sonora indicate the extent of the former seaways. Near El Tigre the Upper Paleozoic limestones attain a thickness of about 5500 feet, are like those in southeastern Arizona, and show the existence of a fairly broad persistent sea. Marked shoaling is indicated by the shaly character of the Upper Mississippian deposits.

Near El Tigre the Paleozoic limestones are overlain by several thousand feet of near-shore deposits representing the Trinity division of the Cretaceous. Significant fossils include *Parahoplites, Acanthoplites, Cheloniceras, Beudanticeras,* and *Exogyra* aff. *latissima* var. *aquila* (Brongniart). Southward from the Bisbee district the Glance conglomerate and Morita formation increase markedly in coarseness and thickness, attaining over 8000 feet along the northern part of the Sierra de los Ajos. Similar coarse clastic deposits, extending from Cabullona to Santa Cruz, show deposition in a geosyncline adjacent to a rising and probably fairly high landmass which lay south of the Bisbee district and west of the El Tigre district. The transgressive character of the Trinity sediments on the Upper Paleozoic limestones suggests that the Jurassic and Lower Cretaceous seas older than Trinity time never extended as far west as Sonora.

During the Laramide revolution the sedimentary rocks of the geosyncline were intensely folded, uplifted, and eroded to a surface of high relief which subsequently was buried by thousands of feet of Tertiary lavas. Extensive steep-angled faulting along north-northwest lines began in middle or late Tertiary time and at present controls most of the topographic features.

INTRODUCTION

During the summer of 1938 reconnaissance studies were undertaken in northeastern Sonora to obtain evidence bearing on possible marine connections between the Mexican geosyncline and the Pacific geosyncline during certain stages of the Mesozoic era. Most of the studies were made in the region of Bavispe and along the international boundary as far west as Santa Cruz, but some were made as far south as Moctezuma. The results for the most part supplement and confirm those made by Dr. Robert E. King (1939) in central and eastern Sonora; they afford a means of comparing that area geologically with southern Arizona and New Mexico; and they extend considerably the general knowledge of geological events in the entire region. Inasmuch as Dr. King has summarized the work of earlier investigators in Sonora, their findings will be referred to in this report only when pertinent to the subject matter.

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Preparation of this report was made possible by financial support from the Geological Society of America. Professor Kellum conceived the idea of the research and is keenly interested in the results. The fusulines have been studied by Professor C. O. Dunbar (1939) of Yale University. The Mississippian brachiopods have been identified by Dr. G. Arthur Cooper, of the National Museum. Thanks are due Mr. R. S. Clinch, a mining engineer at Nacozari, Sonora, for information concerning the presence of limestone near Pilares de Teras and El Tigre. The writer is greatly indebted to Dr. Robert E. King for access to his manuscript on the geology of central Sonora during the course of the field work and subsequently. Mr. Morris C. Minton served as field assistant.

PHYSIOGRAPHIC AND STRUCTURAL SETTING

The physiographic provinces of Sonora have been fully discussed by King (1939), and those of northwestern Chihuahua by Brand (1937).

Although King was acquainted principally with central Sonora and adjoining parts of Chihuahua, his delimitations and descriptions of the provinces apply equally well in northeastern Sonora except for minor details. The physiographic provinces form parallel north-northwest-trending belts which are closely related to the structure of the underlying rocks. Sonora is bounded on the east by the Sierra Madre Occidental province whose surface has been eroded to maturity and which rises to elevations of 5000 to 10,000 feet. The plateau is composed mainly of lava flows which are flat-lying or gently folded and attain 5000 to 6000 feet in thickness. In a few places they are known to overlie folded Mesozoic rocks. The western edge of the Sierra Madre is irregularly incised by westward-draining streams whose base level is thousands of feet below the plateau. These streams are entrenched westward in gorges which constitute the Barranca (gorge) section of King (1939). This section of the Sierra Madre is about 50 miles wide in east-central Sonora but considerably narrower in northeastern Sonora. It ends on the west in a nearly continuous line of west-facing escarpments which in northeastern Sonora lie east of the Río Bavispe, *i.e.*, east of Huachinera, Bavispe, and Oaxaca.[1]

West of the Sierra Madre Occidental is the province of parallel ranges and valleys which includes the remainder of the area dealt with in this report. In contrast to the Sierra Madre province the topography is controlled largely by earth movements. The ridges and valleys follow the major structural trends which are slightly west of north as is indicated by the drainage pattern on the index map (Fig. 1). The mountains are interpreted as blocks raised by thrust or normal faulting on their west side. King's (1939) deductions as to the major structural features of northern Sonora on the basis of his field studies in central Sonora seem to be essentially correct according to observations made by the writer. However, near the international boundary the effect on topography of the north-northwest structural alignment becomes less pronounced, and another topographic and structural alignment appears which trends about west-northwest. This latter alignment the writer believes is related in origin to a Cretaceous geosyncline which bordered a central Sonoran landmass and was intensely folded during the Laramide revolution.

In the areas of dominant north-northwest alignment in northeastern Sonora, most of the faulting appears to be of the normal type. However a high-angle thrust fault may exist along the western side of the granitic Sierra de Moctezuma (Oposura), about 12 miles northeast of Moctezuma,

[1] Details of the physical features of these provinces may be seen on the Sonora map of the American Geographical Society of New York for 1937.

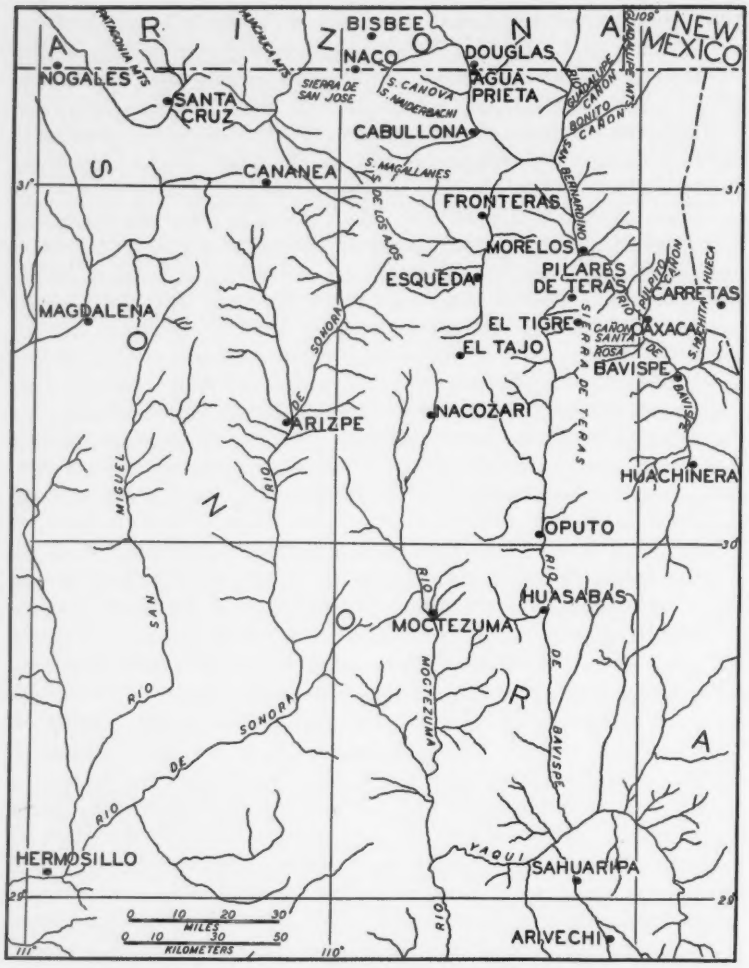

FIGURE 1.—*Index map of northeastern Sonora.*

as lava beds near the mountain dip steeply eastward. The western side of the Sierra de Teras (El Tigre) is marked by a normal fault with a displacement of several thousand feet (Mishler, 1920, p. 586). Some movement has occurred along this fault in recent times. Mining men claim that earthquake fractures dating back to the great Sonoran earthquake of 1887 (Aguilera, 1888; Douglas and Hunt, 1887) are present

along the western foot of the mountain. As a result of faulting the ranges have steep west-facing escarpments and gentler eastern slopes. The escarpments in places expose Paleozoic sedimentary rocks, but in most places consist of granitic or volcanic rocks. The eastern slopes of the ranges are covered with lavas of great thickness, varying in composition from rhyolite to basalt, containing many intraformational volcanic agglomerates, and intruded in places by granitic rocks. Locally near the crests of the ranges, as near El Tigre, eastward-flowing streams have cut through the lava capping and exposed marine sedimentary rocks. The intermontane valleys are underlain by late Tertiary or Quaternary conglomerates called the Báucarit formation. These conglomerates have dips of 10 to 15 degrees on the upper slopes of the valleys and become nearly horizontal toward the middle of the valleys. Much of their dip is probably initial.

The north-northwest fault alignment must be younger than the Laramide revolution as it truncates folds formed at that time (*e.g.*, Teras fault in El Tigre region). As it controls the present topography of much of eastern Sonora and southeastern Arizona, it may be correlated with the Cascadian revolution. Its inception was possibly middle Tertiary.

The west-northwest alignment is dominant near the international boundary from Cerro Cabullona, south of Douglas, westward at least as far as the mountains west of Santa Cruz, and southward as far as the northern part of the Sierra de los Ajos. Taliaferro (1933, p. 35-37, fig. 7) has described an area about 25 miles southwest of Douglas in which the major structural trends are west-northwest. In the Sierra de Cananea immediately west of Cananea the dominant fault and fracture trends vary from west-northwest to northwest (Valentine, 1936, p. 62-64). Southeast of Cananea the writer observed ridges of quartzite which trend southeast into the Sierra de los Ajos. In the northern part of the Sierra de los Ajos the Cretaceous and underlying Upper Paleozoic formations strike west-northwest. The structural trend of the Sierra de San José, a few miles southwest of Naco, appears to be northwest. In the Sierra de los Chivos, east and northeast of Santa Cruz, the strike of the Cretaceous beds is west-northwest. West of Santa Cruz, in the Sierras de San Antonio and Madroño, which are the southern continuation of the Patagonia mountains, the Cretaceous beds trend nearly north at a sharp angle to the beds east of the Santa Cruz river, revealing the contrast between the two dominant structural alignments. However, even in the area of dominant west-northwest trend already outlined, evidence of the presence of the north to northwest trend, which dominates farther north and south, may be seen in the direction of some of the streams (*e.g.*, Río

San Pedro, Río Santa Cruz) as well as in some minor normal faults (Taliaferro, 1933, p. 37; Valentine, 1936, p. 64).

In the areas of dominant west-northwest alignment, folding and thrusting has involved thousands of feet of sedimentary rocks of Cretaceous age which were deposited in a geosyncline to the north of the central Sonoran landmass. The direction of overfolding varies from place to place, as in other strongly compressed geosynclinal belts, but in Sonora it is dominantly toward the southwest. The trend of the folds may be considered as roughly parallel to the landmass (Bucher, 1933, p. 160). This is substantiated near the international boundary by the marked thickening and coarsening of the sediments toward the south. Similar criteria for the El Tigre area indicate that the geosyncline turned southward in eastern Sonora along the eastern margin of the landmass.

All available evidence indicates that the principal folding of the Cretaceous rocks of northeastern Sonora and adjacent parts of Arizona occurred during the Laramide revolution and was completed before Tertiary vulcanism began. In Cañón Santa Rosa near El Tigre the writer noted that the Cretaceous and Upper Paleozoic formations are strongly overturned toward the west and are overlain by several thousand feet of nearly flat-lying lavas whose lower part fills the irregularities of a rugged erosion surface. Similar relations between the Mesozoic sedimentary rocks and Tertiary volcanic rocks were noted by King (1939) in the Chihuahua plateau east of central Sonora. In the Bisbee district at least part of the strong folding of the Cretaceous formations occurred at the end of the Cretaceous or in early Tertiary time (Tenney, 1932, p. 49). South of the international boundary in the region east of Cabullona, volcanic rocks rest on the eroded edges of strongly folded Cretaceous rocks.

STRATIGRAPHY

GENERAL FEATURES

The rocks of northeastern Sonora consist mainly of Upper Paleozoic limestones, Cretaceous clastic deposits, Tertiary lavas, and Quaternary lavas and conglomerates. Pre-Cambrian basement rocks are exposed in a few places in the Cabullona region. Their former wide extent is indicated by abundant fragments of schist and gneiss in the basal Cretaceous beds. Lower Paleozoic rocks of slight thickness, comparable with those at Bisbee, are probably present south of the Bisbee district. Upper Paleozoic limestones crop out over small areas near the crests of the mountains. Lower Cretaceous rocks are extensive along the international border from Santa Cruz to Cabullona. Farther east smaller

FIGURE 1. EASTERN LAVA SLOPE OF SIERRA DE TERAS

FIGURE 2. NORTHERN WALL OF CAÑÓN SANTA ROSA
K = Cretaceous; C = Permo-Carboniferous; Cliffs composed of rhyolitic lava. Relief about 3000 feet. Paleozoic-Cretaceous contact indicated by dashes.

MOUNTAINS AND CANYONS

FIGURE 1. OYSTER-BEARING CRETACEOUS LIMESTONE AT HEAD OF CAÑÓN SANTA ROSA

FIGURE 2. FUSULINE-BEARING PALEOZOIC LIMESTONE IN CAÑÓN DE NOCHE TRISTE NEAR PILARES DE TERAS

LIMESTONES

masses are exposed in the Sierra de Guadalupe and Sierra de Teras. Upper Cretaceous rocks are known only from the Cabullona basin. Tertiary lavas cover vast areas on the eastern slopes of the mountains and underlie late Tertiary or Quaternary conglomeratic deposits in the

TABLE 1.—*Comparison of rock thicknesses in northeastern Sonora and southern Arizona*

Systems	Bisbee district, Arizona (After J. B. Tenney) (thickness in feet)	Cabullona area, Sonora (After N. L. Taliaferro) (thickness in feet)	Sierra de Teras, Sonora (After R. W. Imlay) (thickness in feet)
Quaternary conglomerate			300
Tertiary lavas			5000+
Upper Cretaceous	Absent	8500+	Absent
Lower Cretaceous	4275–5450 (thickens toward south)	6000–8700 (thickens toward south)	2850+
Upper Paleozoic	3700+	2500+ (incompletely exposed)	5510+ (incompletely exposed)
Lower Paleozoic	1540	Probably present	Not exposed
Pre-Cambrian	Pinal schist	Pinal schist	Not exposed

valleys. Extensive tuffaceous sands and shale east of Esqueda were probably deposited in a Tertiary lake prior to the latest basaltic outpouring. The thicknesses of the systems in northeastern Sonora and in Arizona are compared in Table 1.

CARBONIFEROUS AND PERMIAN SYSTEMS

Distribution.—A thick limestone succession of Permo-Carboniferous age crops out over small areas in northern Sonora. The most extensive outcrops, comprising about 10 square miles, are in the Sierra de Teras (El Tigre) at the heads of Cañones Santa Rosa (Pl. 1, fig. 2), Internacional, de Noche Triste (Pl. 2, fig. 2), and in the vicinity of El Tigre. Limestone occurs over an area of similar size in the northern part of the Sierra de los Ajos. A small isolated outcrop occurs farther south in the same range about one mile west of Nacozari (Wade and Wandke, 1920, p. 382-383). Metamorphosed limestone and quartzite have been reported southeast of Nacozari in the Sierra de (Oposura) Moctezuma

(Gonzalez, 1937, p. 312). Taliaferro (1933, p. 18-19) records Carboniferous limestone from the northern part of the Cabullona region southeast of Bisbee, and Mitchell (1928, p. 373) found Carboniferous fossils in the limestones of the Sierra de Cananea. A belt of limestone, com-

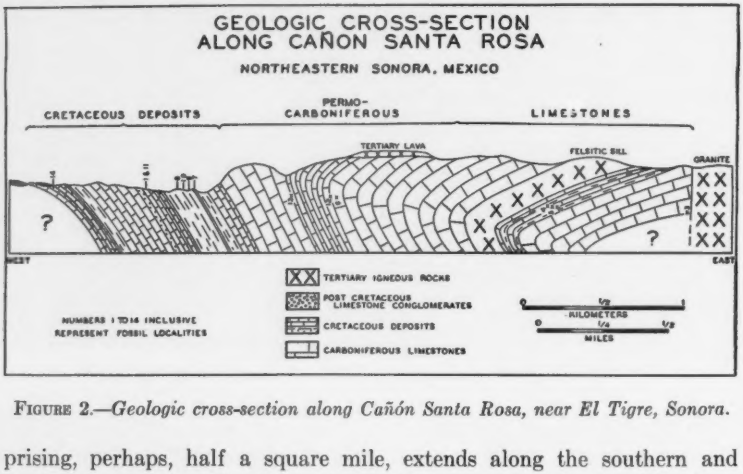

FIGURE 2.—*Geologic cross-section along Cañón Santa Rosa, near El Tigre, Sonora.*

prising, perhaps, half a square mile, extends along the southern and southwestern end of the Sierra de Huchita Hueca northeast of Bavispe. Other small masses of limestone, locally called "dikes", occur in the Sierra Huachinera and at the head of Cañón de Dos Cabezas about 15 miles southeast of Bavispe. All these occurrences probably comprise less than 30 square miles.

The base of the Carboniferous limestone in northern Sonora is not definitely known. Quartzites, presumably older than the limestones, occur in the Sierra de Cananea, along the western side of the Sierra de los Ajos, and in the Sierra de Moctezuma. Some formations in the Cabullona district are considered by Taliaferro (1933, p. 16-18) to be equivalent to the Lower Paleozoic rocks of the Bisbee region.

El Tigre area.—Permo-Carboniferous limestone about 5500 feet thick is excellently exposed along Cañón Santa Rosa a few miles southeast of El Tigre as part of an anticline overturned toward the west (Fig. 2; Pl. 1, fig. 2). It includes five members of which the lowest, middle, and highest consist mainly of thick-bedded limestone containing nodules of chert. The second from the bottom consists of thin-bedded limestone and shale and contains a rich brachiopod fauna. The fourth member from the bottom consists of thin-bedded limestone and considerable

chert. Fusulines are fairly common in the two highest members and in the upper 410 feet of the third member.

The section, determined by pacing, from top to bottom is as follows:

Member	Feet
1. Limestone, thick-bedded, compact, light to dark gray; contains nodules of yellow, cream-colored to black chert which weather whitish; fusulines throughout in many beds, but especially abundant toward base; weathers gray to yellowish gray; upper few feet somewhat brecciated but recemented; upper surface slightly irregular and making a sharp contact with Cretaceous sandstone. Fusuline Coll. Santa Rosa 13 made at base	1155
2. Limestone, thin-bedded, dark gray; many intercalated lenses of light to dark gray chert. Fusuline Coll. Santa Rosa 12 made at base	715
3. Limestone, thick-bedded, compact, light to dark gray; some beds contain nodules of yellow to gray chert; in lower 250 feet occur several units of nodular, thin-bedded limestone and a few lenses of black chert. Fusuline Coll. Santa Rosa 6 made about 120 feet from top. Base of fusuline beds about 410 feet from top	2380
4. Limestone, thin-bedded, and shale. Brachiopod Coll. Santa Rosa 2 made 100 feet above base; Santa Rosa 5, about 150 feet above base; Santa Rosa 4, about 200 feet above base	375
5. Limestone, thick- to medium-bedded, compact, light to medium gray, contains some lenses and nodules of black chert; most beds consist mainly of partly comminuted crinoid stems and bryozoa, and rarely corals and brachiopods. One brachiopod (Coll. Santa Rosa 3) obtained about 80 feet above lowest exposures[2]	885
Total	5510

The brachiopod fauna in members 4 and 5 has been examined by G. Arthur Cooper (personal communication, April 15, 1939), who has made the following identifications:

Coll. S. R. 3 contains a single poorly preserved specimen whose characters suggest relationship to *Echinoconchus* or to *Buxtonia*.

Coll. S. R. 2 contains *Camerophoria?* sp., *Composita* sp., *Eumetria* cf. *E. verneuiliana* Hall, *Dielasma* sp., *Echinoconchus* cf. *E. biseriatus* (Hall), *Spirifer leidyi* N. and P., *Cleiothyridina sublamellosa* (Hall), *Pugnoides* sp. ?, *Composita* cf. *C. trinuclea* (Hall), *Myalina* sp., *Griffithides* sp., indet. bryozoa.

Coll. S. R. 5 contains *Cleiothyridina* sp., *Pugnoides* 2 sp., *Spirifer pellaensis* Weller, *S. leidyi* N. and P.

Coll. S. R. 4 contains *Camerophoria* cf. *C. explanata* (McChesney), *Dielasma arkansanum* Weller, *Diaphragmus* cf. *D. fasciculatus* (McChesney), *Rhipidomella* cf. *R. dubia* (Hall), *Reticularia setigera* (Hall), *Pugnoides* aff. *P. ottumwa* (White), *Eumetria verneuiliana* (Hall), *Spirifer pellaensis* Weller, *S.* cf. *bifurcatus* Hall, *Griffithides* sp., indet. bryozoa.

[2] The Mississippian collections are in the Museum of Paleontology at the University of Michigan. The fusuline types are in the Peabody Museum of Natural History.

Concerning the correlation of members 4 and 5 Cooper says:

"The fossils of lots S.R.2, S.R.5, and S.R.4 all belong to the Ste. Genevieve division of the Mississippian and (probably) should be correlated with the lower part of the Paradise formation (of Arizona) as high as Hernon's third member (1935, p. 655-662). It is doubtful if any of the Mexican material can be placed higher in the section because of the unmistakable Ste. Genevieve characters of collection S.R.4 which is the highest fauna collected. . . . Because of the imperfect nature of the single specimen collected in lot S.R.3, it is impossible to say precisely where the specimen belongs. It is certainly of Mississippian age and in pre-Genevieve rocks."

The fusulines from members 1, 2, and 3 of the section in Cañón Santa Rosa and from other localities have been studied by Carl O. Dunbar (1939). His studies show that members 1, 2, and the upper part of 3, are of Permian, probably Leonard, age, and probably represent a distinct seaway from that which crossed central Mexico and west Texas.

It follows from Cooper's and Dunbar's studies that the Pennsylvanian, if present, must be represented by part of member 3. That the Pennsylvanian is present in northeastern Sonora is indicated by Dunbar's (1939) studies of the fusulines from the Sierra Huchita Hueca.

The Upper Paleozoic limestones of the El Tigre area constitute offshore facies similar to those of southeastern Arizona (Stoyanow, 1936, p. 505-536) and were evidently deposited farther seaward in the same basin. Their characteristics mainly indicate deposition in moderately shallow water at a considerable distance from any land. However, the shales of member 4 indicate marked shallowing of the seas as does its equivalent, the Paradise formation of Arizona (Stoyanow, 1936, p. 511).

Pilares de Teras area.—Several thousand feet of Permo-Carboniferous limestone is excellently exposed along Cañón de Noche Triste (Pl. 2, fig. 2) which drains westward from the Sierra de Teras about half a mile north of the mining village. They are lithologically like members 1, 2, and 3 of the section in Cañón Santa Rosa and are undoubtedly equivalent. The upper two members contain many fusulines which Dunbar (1939) considers are probably of Leonard age. The limestones dip eastward about 30 degrees and are overlain near the head of the canyon by conglomerates and red beds of probable Cretaceous age. They end abruptly on the west in a prominent escarpment whose foot consists of Tertiary basalts and which marks the position of the Teras fault previously mentioned.

Sierra Huchita Hueca area.—A belt of limestone, ranging from a few hundred to about 1000 feet in thickness and dipping about 30 degrees eastward, extends along the southern and southwestern side of the sierra and caps the next to the highest peak. On this peak the upper 200 feet of limestone contains numerous fusulines. Most of the limestone beds

FIGURE 1. PALEOZOIC-CRETACEOUS CONTACT IN CAÑÓN SANTA ROSA
About 600 feet north of bottom of canyon. Paleozoic limestone on left dips about 60° E.–NE.

FIGURE 2. FRONT VIEW OF OUTCROP SHOWN IN FIGURE 1
Hammer head rests on Cretaceous sandstone at contact.

PALEOZOIC-CRETACEOUS CONTACT

FIGURE 1. CRETACEOUS BLACK SHALE WITH LIMESTONE LENSES (FOREGROUND)
About 600 feet north of bottom of Cañón Santa Rosa near head. Limestone lenses consist mainly of *Exogyra* and *Plicatula* shells.

FIGURE 2. CRETACEOUS LIMESTONE AND SHALE IN CAÑÓN SANTA ROSA
South side of canyon near head. Highest hills capped with nearly flat lying lava which rests on a surface of high relief underlain by Cretaceous beds and post-Cretaceous limestone conglomerates.

CRETACEOUS BEDS

are greatly shattered, shot through with igneous sills, more or less bleached, and granular in texture. Dunbar (1939) refers the fusulines of Coll. S. C. 1, obtained about 100 feet below the top, to a Leonard (Permian) horizon. He considers that the fusulines of Coll. S. C. 2, obtained about 200 feet lower stratigraphically, favor a Cisco (Pennsylvanian) horizon. He suggests that the section is probably broken by a fault as the Cisco and Leonard horizons are so close together. The writer considers it likely that the limestones on the western front of Sierra Huchita Hueca have been displaced by thrusting although the principal Tertiary movements involve normal faulting.

CRETACEOUS SYSTEM

Distribution.—Lower Cretaceous rocks crop out rather widely in northern Sonora from Cerro Cabullona, about 15 miles south of Agua Prieta, westward at least as far as Santa Cruz—a distance of about 80 miles. These are similar to, and are correlated with, the Bisbee group of southern Arizona. In Guadalupe Cañón, about 27 miles east of Agua Prieta, occur Cretaceous beds which are a southern extension of a much larger mass in the Guadalupe Mountains of southeastern Arizona and southwestern New Mexico. Small exposures were found by the writer in the Sierra de Teras (El Tigre) (Pl. 1, fig. 2; Pl. 2, fig. 1; Pl. 4) at the heads of Cañones Santa Rosa [3] and Internacional. Outside the area of this report, rocks of probable Lower Cretaceous age were noted by King (1939) at many places in the Sierra Madre of east-central Sonora, and Flores (1929, p. 151-152; Burckhardt, 1930, p. 150) has reported Lower Cretaceous rocks from the region between Hermosillo and Santa Ana. Upper Cretaceous deposits are known certainly in Sonora only from the Cabullona basin (Taliaferro, 1933). Several thousand feet of shale and tuff outcropping extensively a few miles east of Esqueda is probably Tertiary rather than Cretaceous, although no fossils were found in them.

El Tigre area.—The newly discovered section at the head of Cañón Santa Rosa is especially important because it furnishes considerable information about the history of northwestern Mexico during the Upper Paleozoic and the Mesozoic. The section is as follows:

CRETACEOUS SECTION—HEAD OF CAÑÓN SANTA ROSA

Top to bottom (measured by tape)

Cretaceous	Feet
1. Limestone, thick-bedded, gray, contains many oysters, at least	105
2. Shale and limestone interbedded, yellowish, contains many oysters. Coll. 14 contains *Ostrea* n. sp. aff. *owenana* Shumard and *Exogyra* aff. *latissima* var. *aquila* (Brongniart)	23

[3] Variously called La Pita, Santa Rosa, and King, after small ranches.

Cretaceous

Top to bottom (measured by tape)

	Feet
3. Sandstone alternating with thick-bedded limestones	42
4. Limestone, thick- to medium-bedded, gray, contains some oysters	42
5. Sandstone, conglomeratic, some sandy shale and sandy limestone	60
6. Shale, dark gray	8
7. Limestone, thick-bedded, gray	35
8. Shale, black fissile to nodular, dark gray to black poorly exposed	205
9. Limestone, thick-bedded, with many oysters	236
10. Limestone, nodular, gray	20
11. Limestone, thick- to medium-bedded, medium gray, many beds consist mainly of oysters	228
12. Limestone, thick-bedded, interbedded with nodular, thin-bedded, gray, many oyster shells	300
13. Sandstone and shale, yellowish gray	38
14. Sandstone, light yellowish gray	62
15. Limestone, nodular, yellowish gray. Coll. 1 contains *Buccinopsis?* sp., *Pholadomya* sp., *Astarte* sp., *Neithea* sp., *Spondylus* sp., *Ostrea* sp., *Natica* sp., corals, and an echinoid	54
16. Limestone, sandy, nodular, yellow, contains oysters	26
17. Sandstone, yellow, medium- to fine-grained	88
18. Limestone, medium-bedded, gray	35
19. Sandstone, yellow	28
20. Limestone, medium-bedded, gray	14
21. Sandstone as below interbedded with medium- to thin-bedded, gray limestone	39
22. Sandstone, light yellow	32
23. Limestone, thick-bedded, gray	24
24. Shale, fissile to nodular, yellowish gray at base, becoming gray to black higher in section; some thin lenses of yellowish-gray limestone with numerous oysters and a few ammonites. Coll. 9 made 90 feet above base contains *Parahoplites* cf. *uhligi* Anthula, *Parahoplites* sp., *Beudanticeras* sp., *Plicatula* aff. *incongrua* Conrad, *Cucullaea* n. sp., *Acanthoplites* sp., *Exogyra* aff. *latissima* var. *aquila* (Brongniart), and *Cheloniceras* cf. *cornueli* (d'Orbigny); Coll. 8 made 270 feet above base contains *Acanthoplites* (several species), *Parahoplites* cf. *uhligi* Anthula, *Parahoplites* sp., *Beudanticeras* sp., *Exogyra* aff. *latissima* var. *aquila* (Brongniart), *Cucullaea* (two new species), echinoid fragments	537
25. Limestone, thick- to thin-bedded and nodular; some beds contain pebbles of chert and limestone, numerous oysters. Coll. 7 made in same unit about 200 yards to north contains *Exogyra* aff. *latissima* var. *aquila* (Brongniart)	40
26. Shale and sandstone, poorly exposed; shale grayish yellow, fissile to sandy, becoming sandier higher in the section; sandstone, thin-bedded, to shaly, yellowish, calcareous; some beds contain pebbles of chert and limestone and fragments of oysters	210
27. Limestone, medium- to thin-bedded and nodular; some shale partings; a few small nodules of light-gray chert; limestone reddish to yellowish at base, becoming gray higher in section; weathers yellowish to gray, some beds contain oysters	270
28. Shale and sandstone, red, locally conglomeratic	39
29. Quartz sandstone, grayish yellow, friable, overlies Upper Paleozoic limestone which has a slightly irregular surface and is brecciated near the contact	7
Total	2847±

The faunal assemblage shows that the entire section is of Trinity age and, in terms of the European time scale, represents either early Albian or late Aptian. The ammonite genera in unit 24 might indicate either

age, but such species as *Parahoplites* cf. *uhligi* Anthula and *Cheloniceras* cf. *cornueli* (d'Orbigny) indicate upper Aptian. However, none of the ammonite species is represented in the University of Michigan collections from the *Dufrenoya texana* zone (upper Aptian) of north-central Mexico.

The pelecypods do not afford a closer age determination than the ammonites. The common *Exogyra* in the section shows considerable variation in form and sculpture. Some specimens are similar to *E. quitmanensis* Cragin (1893, p. 183) which occurs in the lowest Albian beds of Texas (Adkins, 1933, p. 292-305). The majority differ from the typical form of *E. quitmanensis* Cragin by having a less developed umbo and a more angular, more extensive umbonal ridge which is situated nearer the posterior side of the shell. These specimens greatly resemble *E. latissima* (Lamarck) var. *aquila* (Brongniart) (d'Orbigny, 1847-1849, p. 706, pl. 470) which is common in the Aptian of Europe but ranges into the lower Albian (Pervinquière, 1910; 1912, p. 176-179; Woods, 1913, p. 404). The same common species occurring in Cañón Santa Rosa, Sonora, was collected by Wm. G. Kane in eastern Coahuila at the Potrero de Oballos near Hermanos from beds below the "Glenrose" limestone. It likewise occurs in the *Dufrenoya texana* zone of southern Coahuila and eastern Durango. The excellent preservation of the fossils in the Cañón Santa Rosa section will permit exact correlation when the Trinity faunas of the southwestern United States have been more fully described, but present knowledge suggests that the section is at least as old as the Broken Jug limestone in southwestern New Mexico (Lasky, 1938, p. 531, 535) and the lower Glenrose limestone of Texas.

The lithologic and faunal characteristics of the above section clearly indicates deposition on, or near, the shore of a shallow transgressing sea. The basal 46 feet of conglomerate, sandstone, and shale probably represents reworked mantle rock and soil. The slightly irregular contact with the Paleozoic limestone shows that the pre-Trinity landmass was not peneplained, but the slight brecciation in the upper few feet of Paleozoic limestone does not indicate much depth of decomposition as might have occurred on hilly terrane. As the Trinity section is fairly thick and represents apparently only a part of Trinity time, subsidence must have been rapid. However, the abundance of oysters throughout the section shows that the sea remained shallow. The absence of any volcanic material contrasts with the large amounts of lava in the Lower Cretaceous sections of southwestern New Mexico (Lasky, 1938) and east-central Sonora (King, 1939) and suggests that a different time is represented.

Pilares de Teras area.—Red beds interpreted as basal deposits of the transgressing Trinity sea occur 5 miles north of El Tigre in Cañón de Noche Triste. At this place a thick section of Paleozoic limestone, dipping about 30 degrees east, is overlain concordantly by about 200 feet of conglomerate, sandstone, and reddish shale. The conglomerate consists of poorly rounded pebbles and boulders of quartzite, limestone, and gneiss. Both limestone and red beds are overlain unconformably by nearly horizontal ash and lava beds of Tertiary age.

Sahuaripa area.—Considerable information concerning the position of the landmasses in east-central Sonora has been given by King (1939). On the eastern side of the Sahuaripa Valley the Lower Cretaceous beds attain a thickness of at least 8900 feet, consist of grits, shales, andesitic lava, and limestone, and contain fossils of Albian age. The youngest Cretaceous fossiliferous strata contain a Fredericksburg (middle Albian) fauna and are therefore younger than the Trinity beds of Cañón Santa Rosa near El Tigre. West of Sahuaripa the Cretaceous sediments become less common than Cretaceous lavas, and on the western side of the Rio Yaqui the Cretaceous section apparently consists dominantly of lava. The fauna and lithology of the beds near Sahuaripa indicate near-shore deposits, and King believes that marine waters did not extend much farther west.

Boundary areas.—The Bisbee group of northern Sonora has been described by Dumble (1900, p. 135-137) and Taliaferro (1933, p. 19-22). The latter shows that the lower three of the four formations comprising the group in Arizona (Ransome, 1904, p. 56-73) extend southward into Mexico and that the lower two become much thicker toward the south. The writer studied these formations in the Sierra de San José to the southwest of Naco, and in the hills to the south as far as the lumber camp in the northern part of the Sierra de los Ajos about 25 miles south of Naco. These studies show that from north to south there is a marked increase in coarseness and thickness of the two lower formations of the Bisbee group.

The thickness of the Glance conglomerate in the Bisbee district ranges from 0 to 1500 feet (Tenney, 1932, p. 46); in the Snake Ridge, about 18 miles to the southeast, from 2500 to 3000 feet (Taliaferro, 1933, p. 20); and in the northern part of the Sierra de los Ajos, about 30 miles to the south, it is at least 5000 feet. The Morita formation in the Bisbee district is about 1800 to 2000 feet thick (Ransome, 1904, p. 64); in the Sierra de San José, about 12 miles to the southwest, the incomplete formation is more than 2000 feet thick; in the Snake Ridge the complete formation is more than 5000 feet thick; and in the north-

ern part of the Sierra de los Ajos the formation is at least several thousand feet thick but has not been measured. The characteristics of the Glance conglomerate and Morita formation have been described by Ransome (1904, p. 59-65) and Taliaferro (1933, p. 20-21) and do not differ in the Sierra de los Ajos except for the presence of a coal bed several thousand feet above the base.

Beds similar lithologically to the Morita formation, although somewhat more indurated, occur in the mountains near Santa Cruz. In the Sierra de Los Chivos east and northeast of Santa Cruz is a great thickness of quartzitic sandstone and shale which ranges from gray to pink and red. Some beds are conglomeratic. Northwest and west of Santa Cruz are two low ranges which are the southern extension of the Patagonia Mountains. Only the eastern flanks of these mountains were observed. The Sierra de San Antonio on the north has a core of igneous rock bounded by gray and pink quartzitic sandstone and red shale. The Sierra Madroño farther south exposes several thousand feet of similar rocks, beside considerable quantities of gray shale and a few beds of limestone. Some indeterminable oysters were observed in the latter. Beds similar to those in the region of Santa Cruz crop out in many places on and near the highway leading from Santa Cruz to the Cananea-Naco highway, and apparently form part of the Bisbee group.

The Mural limestone crops out in northern Sonora in a series of west-northwest-trending mountains lying from 5 to 15 miles south of the international boundary. On the east it occurs in Cerro Cabullona (Dumble, 1900, p. 135-137); to the west it forms the crest and northern slope of the Sierra Canova (Taliaferro, 1933, p. 22); farther west it occurs on the southern flank of the Sierra de San José. According to reports, the Mural limestone thickens southeastward from about 650 feet in the Bisbee district (Tenney, 1932, p. 46) to about 1400 near Cabullona (Dumble, 1900, p. 135-136). At the east end of the Sierra de San José the Mural limestone is comparable with that in the Canova mountains to the east and is overlain by a few feet of yellow sandstone which possibly represents the base of the Cintura formation.

The Bisbee group has been correlated by Stanton (Ransome, 1904, p. 70-71) with the Comanche series. The lower member of the Mural limestone contains many fossils which indicate a Trinity age, and the upper member contains a few fossils which suggest a Fredericksburg age. The underlying formations were considered Trinity because they underlie the Mural limestone conformably and are connected throughout by lithologic transitions. Recently Stoyanow (1938, p. 117) has shown the presence of Trinity fossils throughout 900 feet of strata below the Mural limestone. A few fossils of probable Trinity age were collected by the

writer on the south side of Cañón de Mina Oro in the Sierra de San José. About 200 feet below the top of the lower member of the Mural limestone was obtained a large specimen of *Natica pedernalis* (Roemer); about 500 feet below the top were obtained two species of *Trigonia*, of

TABLE 2.—*Suggested correlation of Bisbee group*

European equivalents		Texas groups	Bisbee area	Cañón Santa Rosa area
Lower Cretaceous	Upper Albian	Washita		
	Middle Albian	Fredericksburg	Cintura fm. Mural limestone (Upper member)	
	Lower Albian	Trinity	Mural limestone (Lower member)	?
	Aptian		Morita formation Glance conglomerate	Probably present
	Neocomian			

which one is like *T. stolleyi* (Hill); and about 700 feet below the top were obtained some large thick-shelled oysters. A suggested correlation of the Bisbee group with the Lower Cretaceous of Texas and Europe is given in Table 2.

The great thickness and coarseness of the Bisbee group in northern Sonora indicate deposition in a sinking trough adjacent to a rising and probably fairly high landmass. The source of the sediments lay to the south as shown by increasing thicknesses of deposits in that direction. Deposition must have been fairly rapid as the time represented by the group is but a fraction of the Cretaceous period. The large size and angularity of many boulders in the Glance conglomerate show that temporarily the sea was bordered by steep shores. The presence of finer clastic sediments as well as coal higher in the section indicates times of lowered lands, broader littoral zones, and marginal swamps. Formation of the Mural limestone apparently occurred during a phase of marine transgression over lowered lands. Thickening of this limestone toward the east may indicate the direction of the open sea or that the bordering lands contributed fewer coarse clastic sediments than farther west. The lithologic character of the clastic components of the Bisbee group shows that the landmass to the south was composed of pre-Cambrian gneisses and

schists and Paleozoic quartzites and limestones similar to those outcropping at present in the Bisbee district and locally in northern Sonora.

Margin of Trinity sea.—Enough data is now available to outline approximately the margin of the Trinity sea[4] in eastern and northern Sonora. The submarginal character of the Trinity faunas and deposits near Sahuaripa and El Tigre indicates that the shore line extended northward across eastern Sonora. The possibility of a westward embayment between these areas is precluded by the great thickness of the deposits which proves the existence of a fairly large and rising land mass to the west. The characteristics of the Bisbee group in northern Sonora and southern Arizona show that the Trinity shore line turned westward near El Tigre and traversed the side of the northern part of the Sierra de los Ajos. The distribution of Cretaceous sediments in southern Arizona (Ransome, 1932, p. 9; Stoyanow, 1938, p. 117; Darton, 1925, p. 135-142), in New Mexico (Lasky, 1938), and in northern Sonora indicates that an arm of the sea extended westward along the international boundary as far as the Patagonia Mountains. Whether the sea ended a short distance west of the Bisbee area, as thought probable by Stanton (Ransome, 1904, p. 70), or extended across Sonora can only be determined by additional field work.

TERTIARY SYSTEM

Volcanic rocks.—Lavas aggregating more than 5000 feet in thickness cover vast areas in northeastern Sonora and present features similar to those studied by King (1939) from east-central Sonora. The composition ranges from basalt to rhyolite. Basalt predominates toward the top of the deposits and crops out more extensively than the other types of lava on the eastern slopes of the mountains. Rhyolite and andesite are more common near the crests of the ranges and on the escarpments. Tuff and ash deposits are common. Thick lenticular conglomerate beds composed of volcanic fragments are at many places interbedded with the lavas. Basalt appears more common than in the areas studied by King. The lavas are locally flat lying or gently folded but in most places dip eastward at angles ranging up to 20 degrees.

Detailed studies of lava deposits in northeastern Sonora have been made only near El Tigre (Mishler, 1920, p. 583-586), Nacozari (Wade and Wandke, 1920, p. 382-384), and Cananea (Valentine, 1936, p. 59-60). These studies apparently deal only with the older rocks of the volcanic

[4] Maps showing the principal Mexican localities for late Lower Cretaceous (Aptian-Albian) and paleogeographic interpretations have been made by Burckhardt (1930) p. 212, and Schuchert (1935) p. 171

succession. Near El Tigre occurs about 4000 feet of rhyolitic rocks; near Nacozari occurs 3000 feet of andesites, latites, and rhyolites as flows, tuffs, and breccias; and in the Cananea Mountain occurs thousands of feet of volcanic flows, tuffs, and breccias. All the authors agree that these rocks are probably early Tertiary. King tentatively assigned similar lavas from east-central Sonora and western Chihuahua to the early Tertiary. Possibly some of the basalt flows covering vast surface areas in northeastern Sonora are of fairly recent origin.

The volcanic rocks of northeastern Sonora were deposited on a surface of considerable relief which was underlain by strongly folded Mesozoic and Paleozoic sedimentary rocks and, perhaps, in part by pre-Cambrian and intrusive rocks. In the mountain immediately west of Nacozari the volcanics overlie Paleozoic limestone which occurs as a syncline (Wade and Wandke, 1920, p. 382). In the El Tigre district evidence of an old erosion surface below the lava beds was noticed by Mishler (1920, p. 583). One mile northeast of Pilares de Teras in Cañón de Noche Triste steeply inclined Paleozoic limestone and Cretaceous (?) red beds are overlain by nearly horizontal rhyolitic lavas and tuffs. The best evidence of post-Cretaceous orogeny prior to Tertiary volcanism may be found at the heads of Cañones Santa Rosa (La Pita) and Internacional, a few miles southeast of El Tigre. In Cañón Santa Rosa (Fig. 2; Pl. 1, fig. 2) the Upper Paleozoic limestone is overturned on Lower Cretaceous beds. These sedimentary rocks are cut by an erosion surface with a relief of at least 1000 feet. The depressions on the erosion surface are partly filled with several hundred feet of firmly cemented conglomerate which consists mainly of limestone pebbles and does not contain igneous material. Overlying these conglomerates and pre-Tertiary marine strata is several thousand feet of nearly flat lying lava (Pl. 1; Pl. 4, fig. 2) whose lower part has filled in the irregularities of the old erosion surface. The above relations show definitely that in northeastern Sonora post-Cretaceous folding and erosion occurred prior to early Tertiary vulcanism. This same interpretation was made by King (1939) for the Sierra Madre to the southeast where he observed steeply tilted Mesozoic rocks underlying nearly horizontal Tertiary volcanics and in places protruding into them.

Sedimentary rocks.—Several thousand feet of calcareous shale and tuff crops out along a ridge several miles east of Esqueda and is overlain on the east by a greater thickness of basalt flows. The shale appears to contain considerable volcanic ash. It is soft, fissile, and light gray, yellowish gray, or green. The tuff occurs as highly lenticular deposits ranging from a fraction of an inch to several feet in thickness. No or-

ganic matter was observed. The age of the beds is unknown, but the absence of organic matter, or fossils, and the softness of the beds suggest a Tertiary rather than a Cretaceous age. It is possible that they were laid down in a lake bed such as existed at about that time near El Tigre (Mishler, 1920, p. 583). It seems likely that intermontane lakes were fairly common during the Tertiary period of diastrophism before the present drainage system was well defined.

The lower slopes of the valleys in northeastern Sonora are mantled with several hundred feet of fairly consolidated gravel and sand deposits which dip toward the centers of the valleys at angles of 10 to 20 degrees and form cliffs along the stream courses. Similar deposits in central Sonora were called the Báucarit formation by Dumble (1900, p. 126-128) and by King (1939) and were considered late Tertiary.

QUATERNARY SYSTEM

The rivers of most of northeastern Sonora are actively cutting through the Báucarit gravels and in some places are carving gorges in the lavas. The Bavispe River occupies a narrow gorge about midway between Bavispe and Oaxaca and another near the north end of the Sierra de Teras. In places along the rivers narrow floodplain deposits are being farmed, but elsewhere the alluvium is very thin and consists of coarse sediments in transit. Mature land forms occur locally which have scarcely been affected by the latest erosion cycle, such as a small area north and northwest of Nacozari and a larger area extending from the northern part of the Sierra de los Ajos northwestward to Santa Cruz.

SUMMARY

1. Pre-Cambrian and probable Lower Paleozoic rocks crop out at a few places in northeastern Sonora southeast of the Bisbee district and are lithologically similar to the rocks in the Bisbee sequence.

2. Upper Paleozoic limestones of small areal extent occur at a number of places in northeastern Sonora. Near El Tigre they attain a thickness of at least 5500 feet. Similar thick sections of limestone near Pilares de Teras, in the Sierra Huchita Hueca, and in the Sierra de los Ajos indicate the existence of a fairly broad persistent seaway. The limestones are similar to those in southeastern Arizona but were deposited farther offshore. A marked shallowing of the sea is indicated by the shaly character of Upper Mississippian deposits.

3. Triassic and Jurassic rocks probably do not occur in northeastern Sonora. Evidence obtained by the writer indicates that the Glance and Morita formations of the Bisbee sequence are Lower Cretaceous.

4. Lower Cretaceous rocks outcrop rather widely in northeastern Sonora. Near El Tigre the Upper Paleozoic limestones are overlain by several thousand feet of near-shore deposits of Trinity age. Significant fossils include *Parahoplites, Cheloniceras, Acanthoplites, Beudanticeras,* and *Exogyra* aff. *latissima* var. *aquila* (Brongniart). The Trinity sediments were laid down on or near the shore of a shallow sea which was transgressing westward over a land of moderate relief.

Southward from the Bisbee district the Glance and Morita formations increase markedly in coarseness and thickness, attaining a thickness of more than 8000 feet along the northern part of the Sierra de los Ajos. Similar coarse clastic deposits have been traced as far west as Santa Cruz. The great thickness and coarseness of these formations show deposition of geosynclinal proportion adjacent to a rising and probably fairly high landmass which lay to the south.

The submarginal character of the Trinity faunas and deposits in northeastern Sonora indicates that the shore line extended northward from the region of Sahuaripa to the region of El Tigre and then turned westward at least as far as Santa Cruz.

5. Upper Cretaceous sediments are known for certain only from the Cabullona basin and appear to overlie the Lower Cretaceous unconformably.

6. Toward the end of the Cretaceous or in early Tertiary time the Cretaceous and older sedimentary rocks were strongly folded in directions roughly parallel to the margins of the former landmass. They were then uplifted and eroded to a surface of high relief before Tertiary vulcanism began.

7. Tertiary lavas cover vast areas in northeastern Sonora, where they aggregate over 5000 feet in thickness, range from basaltic to rhyolitic in composition, and are flat lying or gently folded. The oldest lavas are probably early Tertiary and were deposited on a rugged surface. Some of the basalts may be of fairly recent origin.

8. Extensive steep-angled normal faulting along north-northwest lines began in middle or late Tertiary time and has continued to the present. It becomes much greater toward the south and apparently passes into overthrusting in central Sonora. It controls most of the present topography and drainage.

WORKS TO WHICH REFERENCE IS MADE

Adkins, W. S. (1932) *The Mesozoic systems in Texas,* in *Geology of Texas,* vol. 1, *Stratigraphy,* Univ. Texas, Bull. 3232, p. 239-518, 27 figures.

Aguilera, J. G. (1888) *Estudio de los fenómenos seismicos del 3 Maya de 1887,* An. Ministerio de Fomento, vol. 10, p. 5-56.

Brand, Donald D. (1937) *The natural landscape of northwestern Chihuahua,* Univ. of New Mexico Bull., geol. ser., vol. 5, no. 2.

Bucher, W. H. (1933) *The deformation of the earth's crust,* 518 pages, 9 figures, 2 plates.

Burckhardt, Carlos (1930) *Etude synthétique sur le Mesozoïque mexicain,* Soc. Paléont. Suisse, Mém., vols. 49-50, 280 pages, 32 figures, 11 tables.

Cragin, F. W. (1893) *A contribution to the invertebrate paleontology of the Texas Cretaceous,* Texas Geol. Survey, 4th Ann. Rept., p. 139-294, pls. XXIV-XLVI.

Darton, N. H. (1925) *Résumé of Arizona geology,* Univ. Ariz., Bull 119, 298 pages, 74 plates.

D'Orbigny, Alvide (1847-1849) *Paléontolgie française, Terrains crétacés,* vol. 3, 807 pages, 489 plates.

Douglas, James, and Hunt, T. S. (1887) *The Sonora [Mex.] earthquake of May 3, 1887,* Am. Nat., vol. 21, p. 1104-1106.

Dumble, E. T. (1900) *Notes on the Geology of Sonora, Mexico,* Am. Inst. Min. Metall. Eng., Tr., vol. 29, p. 122-152.

Dunbar, C. O. *Permian Fusulines from Sonora,* Geol. Soc. Am., Bull., vol. 50, p. 1745-1760.

Flores, Teodoro (1930) *Reconocimientos geológicos en la región central del estado de Sonora,* Inst. Geol. Mexico, Bol., núm. 49, 267 pages, 212 plates, 7 figures, 28 maps.

Gonzalez, E. M. (1937) *Anuario del Instituto de Geologia 1933-1934,* Univ. Nac. Mexico, Inst. Geol., 348 pages.

Hernon, R. M. (1935) *The Paradise formation and its fauna,* Jour. Paleont., vol. 9, no. 8, p. 653-696.

King, R. E. (1939) *A geological reconnaissance in the northern Sierra Madre Occidental of Mexico,* Geol. Soc. Am., Bull., vol. 50, no. 11, p. 1625-1722.

Lasky, S. G. (1938) *Newly discovered section of Trinity age in southwestern New Mexico,* Am. Assoc. Petrol. Geol., Bull., vol. 22, no. 5, p. 524-540, 4 figures.

Mishler, R. T. (1920) *Geology of the El Tigre district,* Sonora, Min. Sci. Press, vol. 121, p. 583-591.

Mitchell, G. J. (1928) *The geology of Sonora,* Science, n. s., vol. 76, p. 373.

Percinquieère, Léon (1910) *Paléontologie Universalis,* fiche 194.

——— (1912) *Gastropodes et Lamellibranches des terrains crétacés,* in *Etudes paléontologie tunisienne,* vol. II, 352 pages, 23 plates.

Ransome, F. L. (1904) *The Geology and ore deposits of the Bisbee Quadrangle, Arizona,* U. S. Geol. Survey, Prof. Paper 21, 168 pages, 29 plates, 5 figures.

——— (1932) *Ore deposits of the Southwest,* 16th Intern. Geol. Congr., Guidebook 14, p. 1-22.

Schuchert, Charles (1935) *Historical geology of the Antillean-Caribbean region,* 811 pages, 16 plates, 107 figures.

Stoyanow, A. A. (1936) *Correlation of Arizona Paleozoic formations,* Geol. Soc. Am., Bull., vol. 47, p. 459-540, 1 plate, 5 figures.

——— 1938) *Lower Cretaceous stratigraphy in southeastern Arizona,* Geol. Soc. Am., Pr. 1937, p. 117.

Taliaferro, N. L. (1933) *An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico,* Jour. Geol., vol. XLI, no. 1, p. 12-37, 7 figures.

Tenney, J. B. (1932) *The Bisbee mining district,* in *Ore deposits of the southwest,* 16th Intern. Geol. Congr., Guidebook 14, p. 40-66.

Valentine, W. G. (1936) *Geology of the Cananea Mountains, Sonora, Mexico,* Geol. Soc. Am., Bull., vol. 47, p. 53-86, 1 plate, 27 figures.

Wade, W. R., and Wandke, A. (1920) *Geology and mining methods at Pilares Mine,* Am. Inst. Min. Metall. Eng., Tr., vol. LXIII, p. 382-407.

Woods, Henry (1899-1913) *A monograph of the Cretaceous Lamellibranchia of England,* 2 vols. illust. Paleontogr. Soc., vols. LIII-LXVI.

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PERMIAN FUSULINES FROM SONORA

BY CARL O. DUNBAR

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ABSTRACT

Fusulines collected by Ralph W. Imlay from three measured sections in Sonora indicate a considerable thickness of Permian limestone, probably of Leonard age. One collection shows the presence of Pennsylvanian rocks also.

Eight species of fusulines are illustrated, and three new species are named. These are *Parafusulina imlayi, P. skinneri,* and *P. sonoraensis.*

The fusulines indicate that, during Leonard time, Sonora belonged to a faunal province distinct from central Mexico and west Texas.

INTRODUCTION AND SUMMARY

Ralph Imlay transmitted to the writer for study eight collections of fusuline-bearing limestone from Sonora. These are from three distinct localities, as follows:

A. Cañón de Noche Triste, about 1 mile northeast of Mina Pilares de Teras, Sonora.

Coll. P. T. 1. Limestone member 1, about 1000 feet below top of the Paleozoic limestone. *Parafusulina* sp. B.

Coll. P. T. 2. Limestone member 3, about 2000 feet below top of the Paleozoic limestone. *Parafusulina* sp. C.

B. Highest limestone knob at south end of Sierra Huchita Hueca, about 7 miles northeast of Bavispe, Sonora.

Coll. S. C. 1. Top of limestone hill and about 100 feet below highest exposure of Paleozoic limestone. *Parafusulina imlayi* Dunbar, n. sp.

Coll. S. C. 2. West slope of hill, about 300 feet below highest exposure of Paleozoic limestone. *Triticites* sp. A and *T.* sp. B.

C. Cañón de Santa Rosa, about 5 miles southeast of El Tigre, Sonora.

Coll. S. R. 13. About 1155 feet below top of Paleozoic limestone. *Parafusulina* sp. undet.

Coll. S. R. 12. Thin-bedded limestone about 1870 feet below top of Paleozoic limestone. *Parafusulina skinneri* Dunbar, n. sp.

Coll. S. R. 6. Thick-bedded limestone, about 1990 feet below top of Paleozoic limestone. *Parafusulina sonoraensis* Dunbar, n. sp.

Coll. S. R. 6X. Float, about 100 yards from collection S. R. 6 and presumably from about the same horizon. *Parafusulina sonoraensis* Dunbar, n. sp.

Seven of the eight collections include species of *Parafusulina* and are therefore definitely Permian. Since all of these are new, their age must be judged solely by the evolutionary stage attained; this indicates a Leonard horizon.

A single collection (S. C. 2) from the west slope of the highest knob at the south end of Sierra Huchita bears two species of *Triticites* and is probably of Pennsylvanian (Cisco) age.

Although each species of the fusulines is known from only one of the three measured sections, this is probably due to incomplete collecting.

There is nothing in common between these fusuline faunas from Sonora and those of west Texas and the Las Delicias area in Coahuila, and it is therefore probable that Sonora was covered by a distinct seaway representing a faunal province separate from that of central Mexico and west Texas.

SECTION IN SIERRA DE HUCHITA HUECA

Undoubtedly the lowest horizon represented in these collections is that of S. C. 2 at the south end of Sierra Huchita Hueca, which has yielded two small species of *Triticites* and nothing more advanced. Unfortunately, this collection consisted of a single small chip of stone scarcely 2 cubic inches in size, and most of the specimens are silicified so that in thin section they appear glassy and structureless. Although specimens were abundantly scattered through the stone, it was impossible to get sufficient satisfactory sections to permit a formal description of the species. However, there are two quite distinct forms of *Triticites*, both rather small.

Elsewhere in America the genus *Triticites* is limited to the upper "half" of the Pennsylvanian system and to the Wolfcamp horizon at the base of the Permian. In the Pennsylvanian beds this genus normally occurs alone, but in the Wolfcamp horizon it is usually overshadowed by other genera, notably *Schwagerina, Pseudoschwagerina,* and *Paraschwagerina.*

The absence of all these specialized genera, as well as the small size and the simple septa of the two species of *Triticites*, suggest that horizon S. C. 2 is in the Pennsylvanian; it is definitely not older than the Canyon and almost certainly not younger than Wolfcamp. The probability is in favor of an age equivalent to some part of the Cisco group of Texas.

Collection S. C. 1 is characterized by the enormous species, *Parafusulina imlayi*, which is certainly not older than Leonard or younger than Word. The facts that its cuniculi are rather low and narrow and that it is not associated with more advanced cylindical species of *Parafusulina* tend to favor its reference to a Leonard horizon.

If the above conclusions are right, the section at Sierra Huchita Hueca is probably broken by a big hiatus or by a fault, since the Cisco and Leonard horizons are only about 200 feet apart.

SECTION IN CAÑÓN DE SANTA ROSA

In this section the lowest collection, C. R. 6, is almost certainly of Leonard age. The cuniculi of *Parafusulina sonoraensis* are well defined but low and narrow so that it must be considered a rather primitive expression of the genus. As noted in the description, its closest resemblances are to be seen in *P. diabloensis* of the Bone Spring limestone of Texas and in *P. sapperi* of Guatemala.

Collection S. R. 12, only 120 feet higher in the section, has an entirely distinct fusuline fauna, including the long subcylindrical species, *Parafusulina skinneri* and *P.* sp. A. These species have no features that would clearly distinguish between Leonard and Word age; although *P. skinneri* somewhat more closely resembles some of the Word species, the associated *P.* sp. A has more open septal folds, and the age of the bed is probably Leonard.

Unfortunately, the fusulines in collection S. R. 13, the highest in this section, are silicified and so poorly preserved that no satisfactory determinations can be made. The common fusuline is thickly fusiform and has about the size and general shape of *P. sonoraensis*, but internal structure is almost completely lacking.

SECTION IN CAÑÓN DE NOCHE TRISTE

Both collections from this section are in light gray limestone that has suffered extensive recrystallization so that in thin sections most of the fusulines appear as gray ghosts with indistinct structure. At both horizons the fusulines are elongate fusiform and have deeply fluted septa and apparently belong to the genus *Parafusulina*, but the material hardly justifies a formal description. In the lower horizon, P. T. 2, the largest specimens have a diameter of fully 3 mm. and a length of 15 mm., but

neither of these shows internal structure. The specimens figured on Plate 4 are probably immature individuals of the same species or possibly a distinct species.

It is probable that both fusuline zones in this section are of Leonard age, but this conclusion is very tentative.

DESCRIPTION OF SPECIES

Parafusulina imlayi Dunbar, n. sp.

(Plate 1, figures 1-5)

DESCRIPTION.—An enormous, thickly fusiform species of eight or nine volutions, attaining a length of 16 mm. and a diameter slightly more than 5 mm. The shell tends to be flattened or slightly constricted at the middle, and the lateral slopes are convex and taper rapidly to well-rounded poles. The shape changes little during growth, the form ratio tending to increase very slightly, being 2.3 to 2.5 in the inner whorls and 2.5 to 3.1 at maturity. Of the three measured types the first is the largest and the most perfectly oriented and undoubtedly gives the most accurate record of size and proportions. The second is oblique, and the axial length is foreshortened.

The proloculum is near 150 microns in diameter and has a thin wall. The inner volutions are rather closely coiled and thin walled. The rate of expansion is gradually accelerated in succeeding whorls.

The septa are deeply and regularly folded, and the septal loops appear high and crowded in axial sections. Sagittal sections show that the chambers are rather short and the septa abundant, increasing from 20 or more in the second volution to about 40 in the adult whorls. Septal pores are present but difficult to observe, both because of the preservation and because the strong folding causes the septa to cross the thin sections at high angles. Tangential slices show large and well-developed cuniculi.

The tunnel is low and rather narrow and is so obscure in thin sections that it can be measured only in a part of the whorls. The tunnel angle varies between 20 and 30 degrees without any apparent systematic trend. There are no chomata, but a conspicuous belt of secondary deposit appears a short distance on each side of the tunnel, giving rise to two dark parabolas in axial sections. In these rather narrow belts the chambers are partially or completely filled by secondary deposits.

Table of measurements

(in millimeters)

	Half length			Radius vector			Form ratio		
	#1	2	3	#1	2	3	#1	2	3
0	.16	....	.16	.16	.16	.145	....	....	....
1	.70	....	.56	.29	.31	.24	2.5	....	2.3
2	1.40	....	.93	.50	.29	.41	2.8	....	2.3
3	1.90	....	1.39	.71	.44	.61	2.7	....	2.3
4	2.70	....	2.07	1.06	.60	.91	2.5	....	2.3
5	3.60	....	3.21	1.41	.83	1.31	2.5	....	2.4
6	4.90	....	4.50	1.73	1.14	1.71	2.8	....	2.6
7	6.40	....	5.40	2.14	1.45	2.14	3.0	....	2.5
8	8.00	....	....	2.57	1.85	....	3.1	....	....
9	....	....	....	....	2.25	....	....	....	....

	Tunnel angle			Wall thickness			Septal count	
	#1	2	3	#1	2	3	#4	5
1	....	....	....	.020	....	.035	?	15
2	....	....	....	.040	.030	.045	18	26
3	27°	27°	....	.055	.035	.050	19	29
4	....	26°	26°	.085	?	.070	26	30
5	22°	30°	28°	.110	.045	.105	?	34
6	23°	28°	25°	.175	.050	?	32	36
7	27°?	....	....	.115	.105	.115	36	44
8	....	....	....	.101	?	....	41	41
9	....	....	....	....	.070	....	....	....

DISCUSSION.—This enormous species has few equals for size, being shorter but somewhat thicker than any other described species except *P. kingorum*. Its size and shape and the peculiar distribution of its secondary deposits distinguish it readily from any other known species.

OCCURRENCE.—Abundant in a zone about 100 feet below the top of the highest limestone knob at the south end of Sierra de Huchita Hueca, about 7 miles northeast of Bavispe, Sonora.

Parafusulina skinneri Dunbar, n. sp.

(Plate 2, figures 1-7)

DESCRIPTION.—A large, elongate-fusiform species of about seven volutions, attaining a length of about 14 mm. and a diameter of 3.7 mm. The middle is not inflated, and the poles are moderately bluntly rounded.

The prolocula range between 280 and 420 microns in diameter and are normally spherical. The inner volutions are low, closely coiled, and thin walled, the height of the volutions increasing gradually to maturity. The form ratio increases gradually from near 2.5 in the first volution to almost 4.0 at maturity, but the elongate-fusiform shape is attained at an early stage. Figure 6 of Plate 2 is oblique and makes the ends of the shell appear too acute.

The septa are numerous and deeply plicated. Cuniculi are well developed, as shown in Figure 1 of Plate 2. Septal pores are abundant but fine and are easily overlooked because the septa cross the thin sections at steep angles.

The tunnel is low and of moderate width, the tunnel angle varying somewhat irregularly between 30 and 40 degrees.

Moderately massive axial deposits occupy the chambers of the axial region for some distance on each side of the middle of the shell but do not extend into the end zone.

The species is named in honor of John W. Skinner.

Table of measurements

(in millimeters)

	Half length			Radius vector			Form ratio		
	#1	2	3	#1	2	3	#1	2	3
0	.14	.21	.15	.14	.21	.15	....	....	....
1	.71	.79	.44	.29	.33	.20	2.4	....	2.2
2	1.30	1.19	.76	.43	.70	.31	3.0	....	2.4
3	1.85	....	1.46	.61	.96	.46	3.0	....	3.2

	Half length			Radius vector			Form ratio		
4	2.86	....	2.28	.86	1.23	.66	3.3	....	3.4
5	4.21	....	3.70	1.13	1.56	.96	3.7	....	3.8
6	5.14	....	5.10	1.43	1.92	1.31	3.6	....	3.9
7	6.71	....	....	1.83	....	....	3.7	....	....

	Tunnel angle			Wall thickness			Septal count	
	#1	2	3	#1	2	3	#4	5
1	31°	23°	....	....	.025	.025	11	13
2	32°	27°	41°	.025	.030	.025	15	27
3	30°	33°	40°	.035	.045	.040	23	26
4	32°	33°	38°	.050	.060	.075	27	24
5	36°	....	42°	.080	.080	.060	35	26
6	35°	....	40°	.115	.100	.100	37	32
7	37°	....	....	.065	.090	.095	39	?
8	....	....	....	....	....	....	41?	....

Discussion.—This species most closely resembles *P. sellardsi* of the Word formation of west Texas which has a similar shape and a similar distribution of secondary deposits along the axial zone. But *P. skinneri* appears to have normally a smaller proloculum and it does not attain as great size as *P. sellardsi*. Also its tunnel angle is smaller, scarcely exceeding 40 degrees, whereas that of *P. sellardsi* commonly exceeds 50 degrees after the fourth volution; and its septa are less numerous in the outer whorls. There is also considerable resemblance to *P. bakeri* of the Leonard formation, but that species is somewhat smaller, has larger prolocula, and less extensive secondary chamber filling.

Occurrence.—Abundant at a zone 1870 feet below the top of the Permian section of Cañón de Santa Rosa, about 4 or 5 miles southeast of El Tigre, Sonora. It is associated with *Parafusulina* sp. A. The horizon is about 120 feet above that of *P. sonoraensis* n. sp.

Parafusulina sonoraensis Dunbar, n. sp.

(Plate 3, figures 1-8)

Description.—A thickly fusiform species of eight to nine volutions, attaining a length of about 12 mm. and a diameter of nearly 4.5 mm.

The middle of the shell is commonly flattened or slightly constricted, and the lateral slopes converge to rather acute poles.

The prolocula vary greatly in size, ranging from less than 300 to more than 600 microns in diameter. The inner volutions are relatively short, with a form ratio of less than 2.0 in the first whorl, between 2.0 and 2.5 in the second and third, and a tendency to increase in the outer whorls to as much as 4.0 at maturity. The wall is of moderate thickness and is distinctly alveolar.

The septa are deeply and regularly folded in the stage characteristic of *Parafusulina*, with well-developed, but rather small, cuniculi. Septal pores are present, but, due to the silicified condition of all the types, are rather obscure. The septa are numerous and tend to increase from 10 or 12 in the first whorl to 28 or 30 in the second and then gradually increase to 35 or 40 in the outer whorls.

There is a conspicuous zone of secondary deposit along the axis in which the chambers are more or less completely filled with epitheca. This deposit has no very well defined limit and appears to vary considerably in its extent among the types studied.

Table of measurements

(in millimeters)

	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	.33	.20	.25	.17	.30	.20	.25	.17	....	....	....	....
1	.71	....	.57	.43	.44	.29	.33	.34	1.6	....	1.7	1.3
2	1.27	....	1.20	1.01	.63	.41	.51	.46	2.0	....	2.3	2.2
3	1.88	....	1.85	1.43	.87	.60	.73	.66	2.2	....	2.5	2.2
4	2.57	2.0	2.28	?	1.16	.78	.94	.90	2.2	2.6	2.4	2.4
5	....	3.00	2.86	2.85	1.40	.90	1.27	1.19	....	3.3	2.3	....
6	....	4.0	4.00	....	1.69	1.14	....	1.50	....	3.5	....	....
7	....	5.2	....	....	1.98	1.41	....	1.82	....	4.0	....	....
8	....	6.5	....	....	....	1.72	....	....	....	4.0	....	....

	Tunnel angle				Wall thickness				Septal count	
	#1	2	3	4	#1	2	3	4	#6	7
1	?	....	....	....	.030	.035	....	....	12	11
2	22°	....	....	....	.040	.040	....	.035	30	28
3	27°	20°	....	....	.045	?	....	.055	35	31
4	?	....	21°	....	.055	.040	....	.060	36	33
5	27°	23°	....	25°	.075	.060	....	.080	39	36
6	24°	27°	....	28°	.100	.065	....	.090	....	36
7	....	26°	....	....	....	....	....	....	....	....

DISCUSSION.—All the available material including this species is completely silicified, and the specimens are enclosed in solid limestone; hence, the cutting of adequate sections has been difficult, and the illustrations leave much to be desired. At first an attempt was made to separate two species, one constricted at the middle and sharply pointed at the poles, and the other more evenly rounded at the middle and more fully rounded at the poles, but after careful study it was decided that these differences are due in part to accidents of preservation and in part are individual rather than specific. The specimen illustrated as Figure 3 of Plate 3 is considered the holotype.

The resemblance to *P. diabloensis* is striking, not only in size and proportions but in the medial constriction and in the size of proloculum and in the character and distribution of the secondary deposits. On the contrary, *P. diabloensis* expands somewhat more rapidly and has more abundant and more closely crowded septa. It is possible that with more extensive and better preserved material for study these differences would disappear, but the other Sonoran species are unlike those of Texas and evidently represent a distinct seaway and the probability is great that the resemblance of *P. sonoraensis* and *P. diabloensis* is due to convergence.

The resemblance to *P. sapperi* from Guatemala is also noteworthy, but that species is longer and has a wider tunnel angle.

OCCURRENCE.—Abundant in two collections, one from 1990 feet below the top of the Permian section in Cañón de Santa Rosa about 4 or 5 miles southeast of El Tigre, Sonora, and the other from a loose block about 100 yards from the first.

This is probably the lowest of the Permian fusuline zones represented in the collections studied and may be as low as the lower Leonard of central Texas.

Triticites sp. A

(Plate 4, figures 1 and 2a)

DESCRIPTION.—This species is represented by several oblique and random sections and by one section (Pl. 4, fig. 1) almost exactly oriented along the axis but broken by a small fault in the rock. The shell is evenly elliptical in axial profile, having evenly arched lateral slopes and rather acute poles.

In this section the proloculum is very small and elongate, having a diameter in the sagittal plane of 58 microns and a length of 100 microns. The shell had a diameter of about 2.4 mm., a length of about 5.6, and consisted of approximately eight volutions. The radius vector measures .057, .089, .143, .24, .41, .64, .91 and 1.21 mm., respectively, in the eight volutions. The half length can be measured only in the first six volutions where it amounts to .17, .26, .49, .71, .93, and 1.39 mm., respectively.

The tunnel angle measures 29 degrees in the fourth volution and 28, 25 and 24 degrees, respectively, in the fifth to seventh. The tunnel is bordered by well-defined chomata, and the septa are slightly folded except in the end zone. The wall is distinctly alveolar, consisting of tectum and keriotheca.

There is no described species with which significant comparison can be made.

OCCURRENCE.—Collection S. C. 2, 300 feet below the highest exposure of the Paleozoic limestone in the section at the south end of Sierra de Huchita Hueca. Associated with *T.* sp. B.

Triticites sp. B

(Plate 4, figure 2b)

DESCRIPTION.—The commonest species in collection S. C. 2 is a small rotund *Triticites* having a length of about 5 mm. and a diameter of about 3.5 mm. and including seven or eight volutions. The best specimens found are entirely silicified and cannot be successfully photographed, though one of them can be measured rather accurately under proper illumination. Two of these specimens were standing out in relief on the rock, and their external form was studied before sectioning. They were evenly rotund with the exception of small, acute polar projections. A single section of an obliquely deformed specimen in a nonsilicified condition is shown in Figure 2a of Plate 4.

Measurements from the best axial section indicate for the proloculum a diameter of 170 microns and for successive volutions a radius vector of ?, .31, .51, .79, 1.13, 1.43 and 1.71 mm., respectively. The corresponding half lengths are ?, .43, .64, .89, 1.30 and 1.85 mm., respectively.

Chomata are well defined, and the tunnel angle increases from 21 degrees in the fourth volution to 28 degrees in the fifth and 36 degrees in the sixth. Parts of two volutions which are not silicified show that the wall is made of tectum and a well-defined keriotheca. The septa are moderately folded near the ends but nearly plane across the middle of the shell.

DISCUSSION.—This species is exceptionally rotund for the genus *Triticites*, resembling in shape *T. plummeri* of the Cisco group of central Texas, but the septa in that species are more deeply folded, its proloculum is smaller, and its tunnel angle much narrower.

OCCURRENCE.—Associated with *Triticites* sp. A in collection S. C. 2, about 300 feet below the highest exposures of the Paleozoic limestone in the section at the south end of Sierra de Huchita Hueca.

Parafusulina sp. A

(Plate 4, figures 7, 8)

DESCRIPTION.—Associated with *P. skinneri* is a large species represented by three sections, one sagittal, one axial, and another oblique. Although externally resembling *P. skinneri*, this species is quite different internally. It has a larger proloculum, fewer and more loosely coiled volutions, and less axial filling. Moreover, its septal loops are not so narrow or so crowded.

The best axial section is slightly oblique but not enough to effect the measurements seriously. It has a length of nearly 13 and a diameter of 3.5 mm. and consists of about six volutions. Its proloculum has a diameter of 440 microns; its tunnel is not clearly defined in this section, but the tunnel angle appears to be about 30 degrees in the fourth volution. In the sagittal section the proloculum measures 315 microns in diameter, and the septa number 14, 21, 28, 27, 26, 32, and 34 in successive volutions.

DISCUSSION.—This species resembles *P. bakeri* of the basal Leonard of the Glass Mountains in size and proportions, but its septal loops are broader and less crowded. It also resembles *P. fountaini* of the Bone Spring limestone of west Texas but tapers less toward the poles and has less crowded septal loops. It is somewhat larger and less inflated at the middle than *P. bösei* of the Word formation and it apparently has a much narrower tunnel.

OCCURRENCE.—Associated with *P. skinneri* in collection S. R. 12 near El Tigre, Sonora.

Parafusulina sp. B

(Plate 4, figures 5, 6)

DESCRIPTION.—Although the rock of collection P. T. 1 is filled with this species, most of the specimens are so badly recrystallized that thin sections are unsatisfactory. A single axial and a sagittal section are figured.

The axial section shows a specimen about 9 mm. long and 3.2 mm. thick, consisting of about six volutions. Its proloculum has a diameter of 200 microns, and the radius vector of the first five volutions measures .21, .36, .60, .81, and 1.23 mm., respectively. The half lengths of the first five volutions measure .43, .86, 1.43, 2.14, and 3.21 mm., respectively.

The tunnel is apparently narrow, but its limits are too obscure to measure. The septa in the first four volutions number 12, 16, 27, and 26, respectively. They are deeply and regularly folded, and one bit of a tangential slice indicates the presence of small, narrow cuniculi.

DISCUSSION.—Although somewhat resembling *P. skinneri*, this shell has a smaller proloculum, is relatively thicker, and its outer volutions expand more rapidly. Also, it does not have axial filling.

OCCURRENCE.—Abundant in collection P. T. 1, 1000 feet below the top of the Paleozoic limestone in Cañón de Noche Triste, about 1 mile northeast of Mina Pilares de Teras, Sonora.

Parafusulina sp. C

(Plate 4, figures 3, 4)

DESCRIPTION.—The rock of collection P. T. 2 is filled with elongate fusiform fusulines of rather large size which have been badly altered by recrystallization. Two immature axial sections are figured on Plate 4. The largest specimens seen in the rock are about 15 mm. long and 3 mm. thick.

Of the figured specimens, the larger one measures about 9.7 mm. long and 2.8 mm. thick and includes about six volutions. The septa are deeply and regularly folded, and one tangential slice clearly indicates the presence of cuniculi.

Although somewhat like the immature shell of *P. skinneri*, this form appears to be distinct, being thickest at the middle and tapering gradually to the poles, whereas that species tends to be constricted at the middle and is more nearly subcylindrical.

OCCURRENCE.—Collection P. T. 2, about 2000 feet below the top of the Paleozoic limestone section in Cañón de Noche Triste, 1 mile northeast of Mina Pilares de Teras, Sonora.

YALE UNIVERSITY, NEW HAVEN, CONN.
MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, JULY 19, 1939.

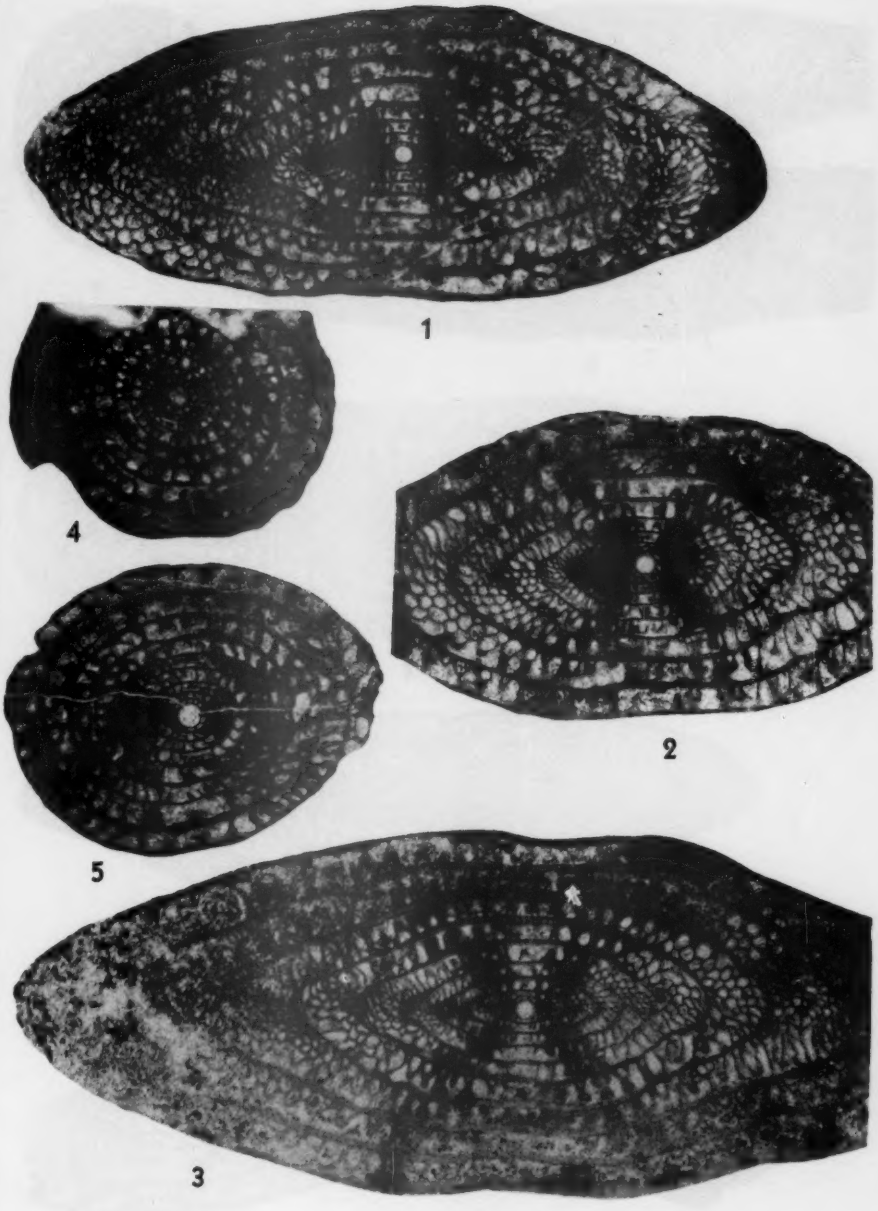
Explanation of Plates

PLATE 1

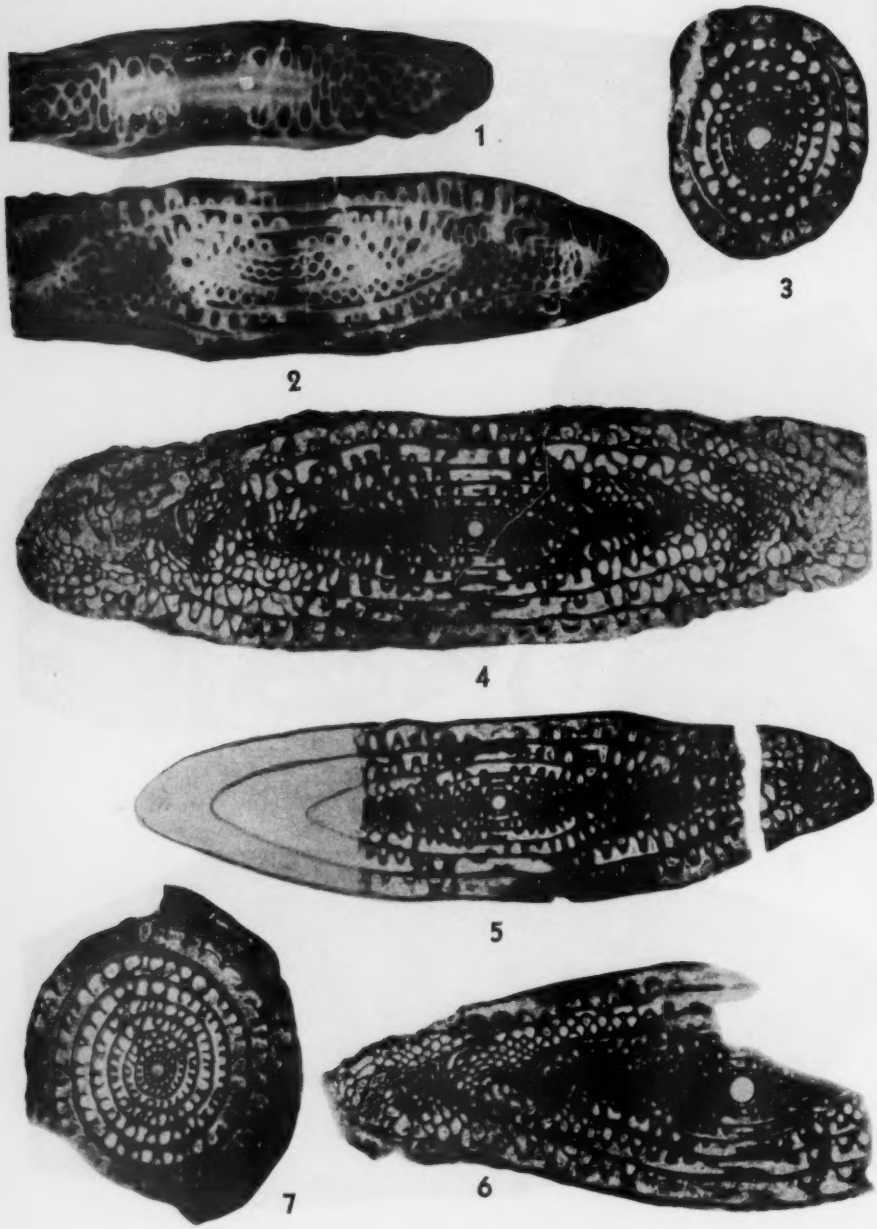
Page

Parafusulina imlayi Dunbar, n. sp..... 1748

Figures 1-3. Axial sections; and 4 and 5, sagittal sections (all × 10). Sections 2 and 5 are oblique. Specimen 3 is the holotype. All from collection S. C. 1, about 100 feet below the top of the Paleozoic limestone section at the south end of Sierra Huchita Hueca, about 7 miles northeast of Bavispe, Sonora.



PARAFUSULINA IMLAYI



PARAFUSULINA SKINNERI

PLATE 2

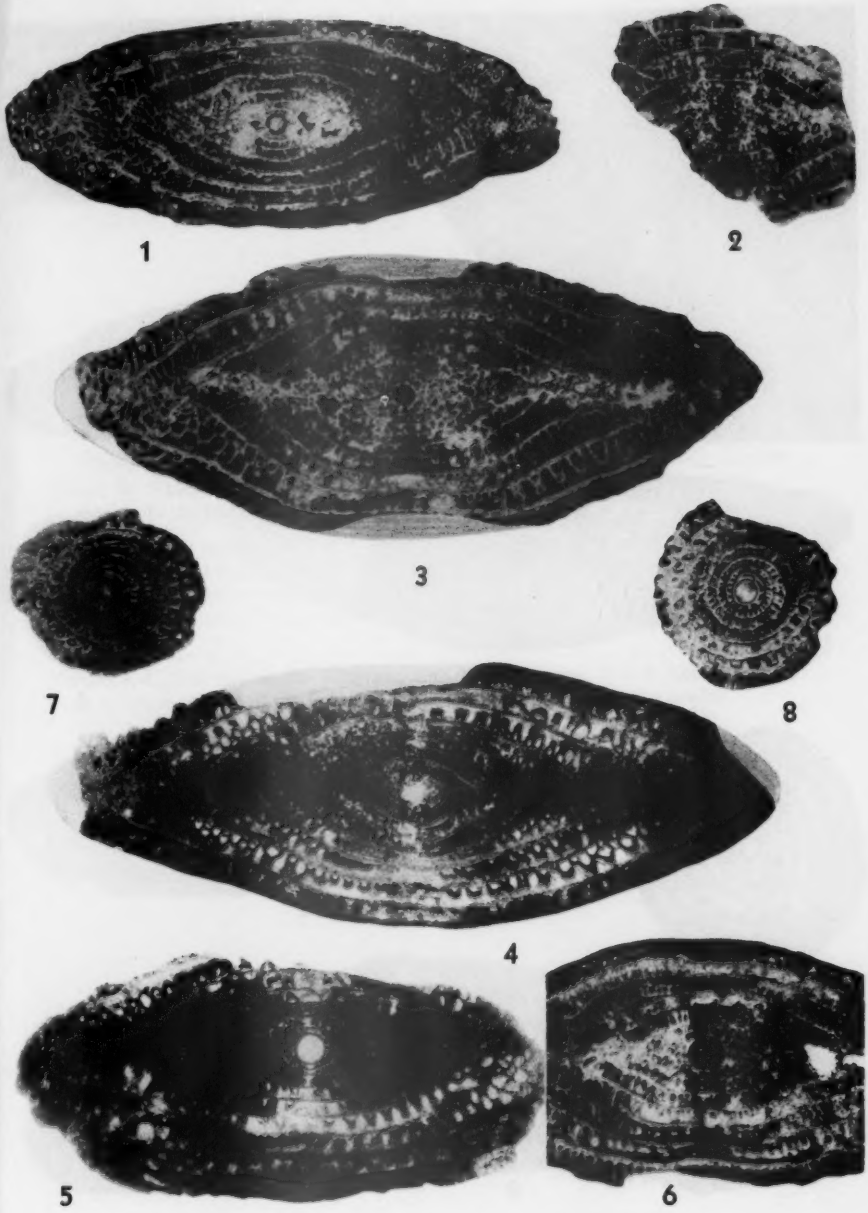
Parafusulina skinneri Dunbar, n. sp..... 1749

Figure 1. Tangential polished surface showing cuniculi; 2, deep excentric axial section of the same specimen; 4, 5, axial sections; 6, oblique axial section; 3, 7, sagittal sections (all × 10). Specimen 4 is the holotype. All from collection S. R. 12, 1870 feet below the top of the Paleozoic limestone section in Cañón de Santa Rosa, about 4 or 5 miles southeast of El Tigre, Sonora.

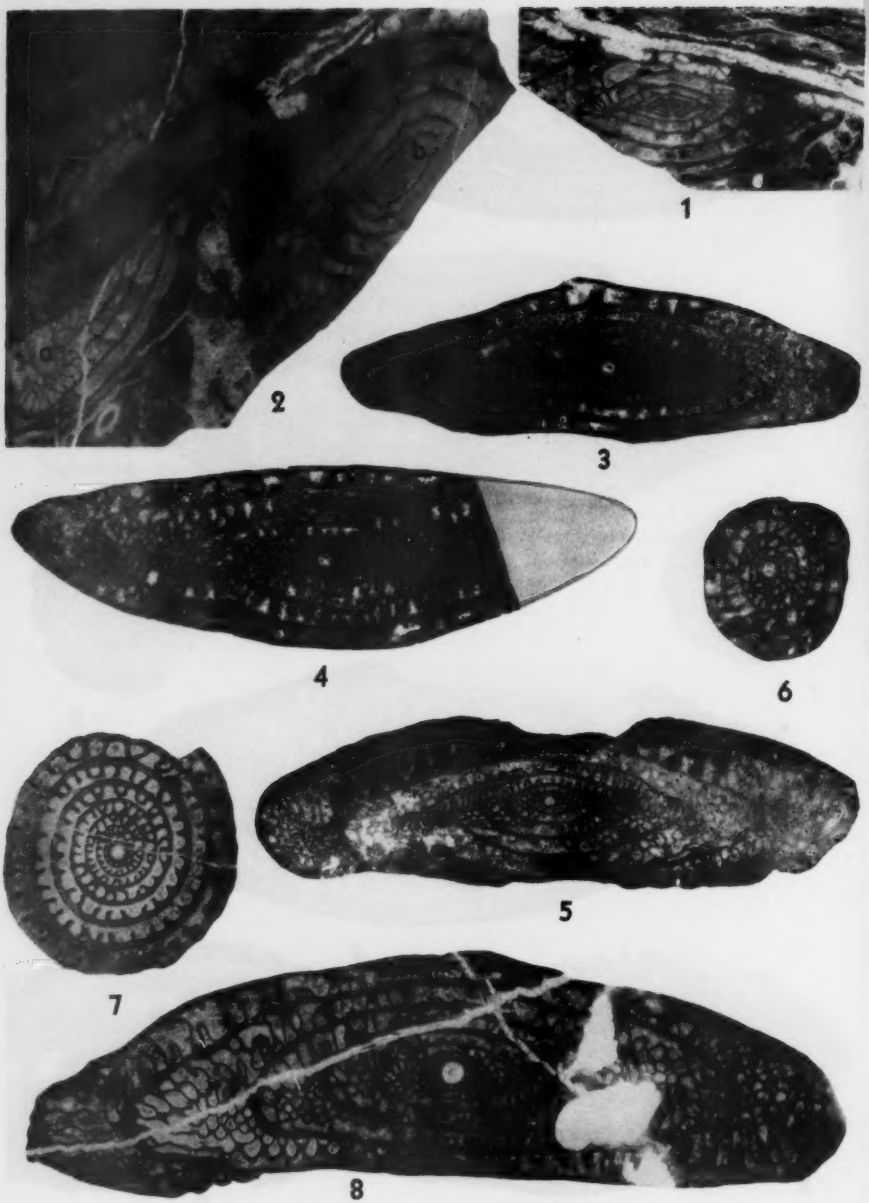
PLATE 3

Parafusulina sonoraensis Dunbar, n. sp..... 1750

Figures 1-6. Axial sections; 7, 8, sagittal sections (all × 10). All but specimens 4 and 5 are from collection S. R. 6, 1990 feet below the top of the Paleozoic limestone section in Cañón de Santa Rosa, about 4 or 5 miles southeast of El Tigre, Sonora. Specimens 4 and 5 are from a loose block presumably from the same horizon and about 100 yards from the site of S. R. 6.



PARAFUSULINA SONORAENSIS



TRITICITES sp. A and B.; PARAFUSULINA sp. A., B., C.

PLATE 4

Triticites sp. A. 1752

Figure 1. Axial section (× 10); 2a, oblique and faulted section (× 10). Collection S. C. 2, about 300 feet below the top of the highest limestone knob at the south end of the Sierra de Huchita Hueca, about 7 miles northeast of Bavispe, Sonora.

Triticites sp. B. 1752

Figure 2b. Excentric axial section of an obliquely crushed specimen (× 10) from the same locality as the last.

Parafusulina sp. C. 1753

Figures 3, 4. Axial sections (× 10) of immature specimens. Collection P. T. 2, 2000 feet below the top of the Paleozoic limestone section in Cañón de Noche Triste, 1 mile northeast of Mina Pilares de Teras, Sonora.

Parafusulina sp. B. 1753

Figures 5, 6. Axial and sagittal sections (×10) from collection P. T. 1, 1000 feet below the top of the Paleozoic limestone section at the above locality.

Parafusulina sp. A. 1753

Figures 7, 8. Sagittal and axial sections (× 10) of specimens from collection S. R. 12, 1870 feet below the Paleozoic limestone section in Cañón de Santa Rosa, about 4 or 5 miles southeast of El Tigre, Sonora.

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CATSKILL FACIES OF NEW YORK STATE

BY ELY MENCHER

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ABSTRACT

The Catskill facies of continental sediments consists principally of graywackes interbedded with conglomerates and of red sandstones and shales with a small percentage of green and dark shales and massive conglomerates. The Catskill sedimentation was introduced in early Hamilton times and represents a great series of alluvial-plain deposits laid down upon the land surface at the base of the re-elevated Taconic Mountains and grading into the sediments of an inland sea. The red shales are interpreted as flood-plain and deltaic subaerial topset beds into which the graywackes of the alluvial plain graded. Continental conditions of deposition were exaggerated as the Upper Devonian progressed, for the Katsberg beds in the east are increasingly conglomeratic.

The Catskill deposits are characterized by the extreme angularity of the grains of the sandstones. The pebbles of the conglomerates, on the other hand, are well rounded.

Barrell contended that the Catskill sediments were derived in the main from the western limits of the old Appalachian landmass, thus placing the source rocks to the southeast and east in an area now covered by Connecticut coastal plain deposits. The present author disagrees with this viewpoint and claims that the sediments had their origin in a near-by source to the north and east. The Taconic Mountain area is the most likely source, for it is situated in a suitable location and contains metamorphic rocks and quartz veins of similar character to the grains making up the graywackes and conglomerates. Moreover, sufficient evidence from structural considerations can be adduced to support strongly the hypothesis that orogenic forces were active in the Taconic area during Middle to Late Devonian.

In early Hamilton times the first orogenic movements began. These raised western New England above the shallow early Devonian seas and started the cycle of continental deposits. Short, rapid streams carried large amounts of detritus from the highlands and dumped their loads quickly on emerging upon a flat shore at the base of the mountains. Gradually an alluvial plain was built out and as the sea moved back, due both to further uplift and to the deposition of alluvial materials, an intermediate zone of flood-plain and delta materials developed between the alluvial plain and the sea. In this intermediate zone were deposited the red sediments that gave rise to the red beds. As time progressed, the shore line varied as did the depositional zones. Periods of quiescence or aridity moved the red-bed zone closer to the foot of the mountains, while renewed uplift increased the area covered by the coarse, angular deposits. Orogenic movements continued throughout the Upper Devonian with increasing vigor. There is no evidence to indicate an arid climate during the Middle and Upper Devonian, and the abundance of plant remains in the graywackes suggests a temperate climate with moderate but seasonal rainfall.

INTRODUCTION

The Catskill Mountains form one of the most impressive physiographic units of New York State, and over 150 papers have been published dealing with the rocks that constitute them. Nevertheless, few papers contain a careful description of these rocks, and there is no completely detailed description of their mineralogy, petrography, and field relationships. The present paper is an attempt to supply this information and to draw valid conclusions concerning the conditions at the time of formation of the Catskill sediments.

The Catskill facies of continental deposits outcrops in southeastern New York State and continues south into Pennsylvania (Figs. 1 and 2). In this paper only the deposits north of the Pennsylvania-New York boundary line will be discussed.

The Catskill facies derives its name from the Catskill Mountains of

New York State. These are not true mountains in the sense of being built of deformed strata but are a dissected plateau and actually represent the northernmost extent of the Allegheny Plateau. Although the

FIGURE 1.—*Eastern New York and western New England*
Showing general relationships of the areas discussed in this paper. (After Longwell, 1933, p. 3.)

strata are essentially horizontal, they dip slightly to the southwest, thus conforming to the general structure of the underlying Devonian rocks which outcrop to the north, east, and southeast. The eastern and northern edges of the Devonian strata are truncated where they formerly overlapped upon the old landmass from which the sediments were derived, and the resistant beds have resulted in a series of cuestas with the Hudson and Mohawk valleys as the inner lowlands.

The Lower and early Middle Devonian of New York consists of sediments of marine origin, and the upper Middle Devonian began with a marine deposit (Marcellus) also. The Marcellus shales are black bituminous fossiliferous shales, but above them the deposits become more coarsely clastic, and in the east continental sedimentation began before the end of the Middle Devonian. Above the Marcellus all the formations show a coarsely clastic phase, either marine, brackish-water, or continental in origin in the east grading into finer-grained wholly marine sediments in the west. The Middle and Upper Devonian of Eastern New York State has been correlated with the marine beds farther west by Chadwick (1933, p. 480) as follows:

East	West
Slide Mountain	Lower Chemung
Katsberg	Enfield
Onteora	Oneonta (type) Otselic Sherburne Tully
Kiskatom Ashokan Mt. Marion Bakoven	Hamilton

It is not the purpose of this paper to enter into any discussion of the stratigraphy of the region, but the use of the term "Catskill" must be made clear. Ever since Mather (1840; 1841) introduced the "Catskill Mountain Group" in 1840, modified by him a few years later (Mather, 1843), the exact correlation of the Catskill beds has been a problem. In general the base of the Catskill has been taken as the lowest red beds. However, since the continental deposits were derived from a mountainous area to the east and northeast and as this was an area that was continually rising and perhaps moving westward during Hamilton and late Devonian times, it is not at all surprising that the beginnings of continental sedimentation should vary from place to place and that the "Catskill" of eastern New York should correlate with earlier beds than the "Catskill" of Pennsylvania as shown by Willard (1933, p. 500). Williams (1881, p. 186-191; 1900, p. 594, 595) early recognized that the Catskill was not a true formation upon which a unique time range could be placed, and later workers have been writing more and more of the "Catskill facies" or the "Catskill type of sedimentation". In this paper such a significance has been adopted, and the word "Catskill" will be used to mean a type of deposit characterized by a nonmarine origin (regardless of color) and ranging from Middle Devonian through Chemung. The base of the Catskill will therefore go below Chadwick's Kiskatom and

into the Ashokan flags, the first Hamilton formation of continental character (and possibly even below this into the Mt. Marion beds in certain areas).

The most important paper dealing with the problem of the sedimentation of the Catskill beds was published by Barrell (1913, p. 429-472; 1914, p. 87-109, 225-253). He gave a fairly complete account of the Catskill beds and related formations. The actual description, however, dealt mostly with sections along the Schuylkill in northeastern Pennsylvania where there is a greater proportion of red beds than in the New York Catskill and where the strata are younger than in most of the New York area. The conclusions Barrell reached are briefly these:

The Catskill beds were deposited as the subaerial topset beds of a large delta forming along the northeastern part of a shallow Appalachian geosyncline. The Chemung and other marine beds were the subaqueous topset beds into which the land deposits graded. The source of most of the sediments was from the east but most particularly from the southeast from the western part of the old Appalachian landmass. The source was therefore about 200 miles from the easternmost part of the deposit. The Skunnemunk conglomerate, in its outlier 25 miles southeast of the Catskill front, represented the piedmont gravel plain that continued to the base of the mountains. The materials were deposited by a series of short streams somewhat in the manner of a number of coalescing fans and not by one or two large rivers. The areal extent of the deposits was a good deal farther east than the outcrops now show. The Atlantic faunal province was connected with the Appalachian faunal province by a northern seaway rather than a southern one (as was usually inferred by other geologists at the time). The climate was warm with seasonal rainfall. Comparable formations are the Siwalik of India and the more recent Indo-Gangetic plain deposits (which in a former paper Barrell (1906) had used as a type for his piedmont river deposits) and the Tertiary to Recent alluvial deposits facing the Rocky Mountains.

Barrell based his conclusions on a study of the general field relationships of the formations, the character of the various rocks and their gradations, and the sedimentary structures present, such as cross-bedding, ripple marks, and mud cracking.

No later worker has ever questioned Barrell's assumptions except on one or two points, and then not directly. It has been frequently stated that the Catskill deposits came from the Taconic area of New York State and western Massachusetts. For instance, Miller (1924, p. 58) in his summary of the geological history of New York State, remarks,

"The Catskill rocks are clearly land derived sediments which were washed into the Devonian sea by streams from the Taconics, and also probably from land areas which are known to have existed to the north in Canada."

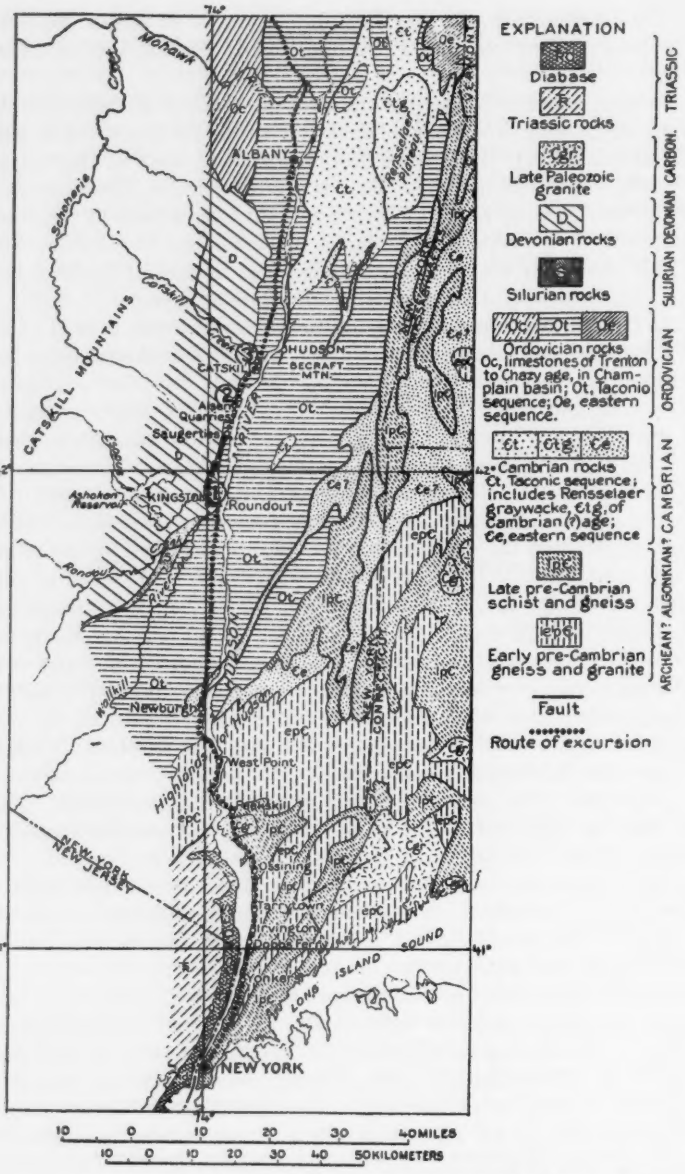

FIGURE 2.—*Geologic map of area east of the Catskill Front*
(After Longwell, 1933, Pl. 1.)

Such reports usually overlook the pains to which Barrell went to disprove the existence of a northern landmass or a rise in the Taconic Mountains in Acadian times. Miller produces a series of anomalous conditions, for he disregards the Acadian as a period of mountain building in the New York rocks and yet derives his Catskill sediments from highlands of Acadian age. As there is little doubt that the Taconic area was low land, if not submerged, during Early and perhaps early Middle Devonian times, it is essential to postulate at least a rise of the area during Middle and Upper Devonian. Other geologists have taken the presence of the thick Catskill deposits themselves to indicate a high Taconic landmass. To make such an assumption, however, it is first necessary to disprove Barrell's contention that the deposits were derived from ancient Appalachia, much farther to the east than the Taconic Mountains.

On the other hand, if evidence is adduced for uplift of the Taconic area in Acadian times, this would considerably weaken the force of Barrell's assertions, for it would then be impossible for the sediments to have been derived from east of this landmass.

The present paper will concern itself with a consideration of these points. An attempt will be made to show that the sedimentary evidence indicates a much closer source for the deposits than that postulated by Barrell and that structural and general considerations point strongly to a period of orogeny from Middle to Upper Devonian in western Massachusetts and eastern New York. The advisability of the use of the term "delta" for the whole of the deposit will also be questioned.

ACKNOWLEDGMENTS

The author wishes to express his thanks to Dr. Hervey W. Shimer at whose suggestion and under whose supervision this work was undertaken, and his appreciation of the aid given him by various members of the faculty and staff of the Geology Department of the Massachusetts Institute of Technology.

THE ROCKS OF THE REGION

GENERAL DESCRIPTION

The Catskill facies consists of graywackes, red sandstones and shales, green and dark shales, and conglomerates. While it is customary to refer to the deposits as "red beds", actually the proportion of red rock is less than 10 per cent. The graywackes are the thickest deposits, but they are dull blue, gray, or green and hence do not strike the eye as do the red beds. In addition, the rapidly weathering red shales result in a red clay that sifts down over much of the gray sandstone causing the gray beds to appear red under superficial observation. Ordinarily, too, the gray-

wackes weather to a reddish sandstone and, in some cases, to a red shale very hard to distinguish from the true red beds of the area. Thus, the amount of the true red beds present may be easily exaggerated.

The graywackes are various shades of gray, green gray, or blue gray. They range from fine-grained sandstones grading into shales to conglomerates. The character of the graywackes changes rapidly both vertically and laterally. Thus it is not uncommon to find a coarse graywacke grading laterally within 10 or 20 feet into a green and red variegated arenaceous shale or upward into a conglomerate with pebbles of vein quartz, quartzite, and slate. The pebbles are usually well rounded and are in marked contrast to the matrix material, which is coarsely angular. Often the conglomeratic layers are not true conglomerates but consist of a relatively few scattered pebbles in the grit. Frequently layers in the graywacke contain abundant fragments of dark or red shale; many of these layers represent intraformational conglomerates formed by the erosion and redeposition of newly formed shale beds. Cross-bedding is everpresent in the graywackes, and banding sometimes occurs.

The red beds consist of shales and sandstones interbedded with the graywackes particularly in that part of the Catskill deposits classified as Kiskatom by Chadwick. The red sandstone beds rarely attain a thickness of a few feet and are invariably interbedded with the red shales. Crow's-nest ripple marks and cross-bedding on a fine scale are rare. The red shales occasionally are stream-ripple-marked and are mud cracked.

Neither the green nor the dark shales occur in thick beds but represent grain-size variations of the graywacke or transition zones from the graywacke to the red beds. The green shales are limited to the lower part of the series where there are frequent variations from coarse graywacke to fine graywacke to green arenaceous shale to green shale. Dark-gray shales frequently occur as lenses in the graywacke and are sometimes cross-bedded with the sandstones. The green shale is sometimes present as a very thin but persistent layer in the red shale, and where the graywackes grade into red sandstones or shales there may be intermediate zones of variegated green and red arenaceous shales or of intermingled red and green argillaceous shales.

The conglomerates occur typically in the higher beds represented by the Katsberg of Chadwick but are present also in many lower horizons. Throughout the whole series, even in some of the Kiskatom beds, are conglomeratic layers. The proportion of quartz pebbles in these conglomeratic layers is high, but an examination of pebbles from such a layer between Haines Falls and Palenville revealed various types of quartzite and metamorphosed clay rocks, some cut by small quartz veins.

The Catskill sedimentation began in eastern New York early in Hamilton time. After the deposition of the lowest of the highly fossiliferous Hamilton shales the type of deposit started to change, and finally continental conditions prevailed. The transition was gradual in many places with brown shale giving place to green shale interbedded with fine-grained flags (graywacke) with the sand content increasing until sandstones of the Ashokan type predominated. At other localities the change was more abrupt, and somewhat massive graywacke lies on an eroded brown shale surface. These lowermost graywackes belong to the Ashokan group and are fine-grained, compact, dark, exceedingly cross-bedded rocks containing plant remains. There are some concretionary layers present possibly due to a slightly higher lime content. The first red bed in the succession arbitrarily marks the beginning of the Kiskatom deposits which are characterized by their relatively great proportion of red sediments. Innumerable successions of graywacke to red shale to graywacke occur as one goes higher in the column. In the Onteora beds the proportion of red materials is greatly decreased, while the graywackes become coarser. The Katsberg does not outcrop at the Catskill front, but the more easterly Katsberg deposits are coarser sandstones and conglomerates gradually becoming finer-grained, more homogeneous, and regularly bedded toward the west. The conglomerate capping Slide Mountain lies on top.

The graywackes and red shales and sandstones are interbedded, but the gray beds are ordinarily much thicker than the red. Except for a section about midway in the Kiskatom sedimentation where the red beds attain unusual thicknesses, the separate red beds rarely exceed 10 or 15 feet, whereas the gray beds may be as much as 100 feet thick. Sometimes the gray sandstones grade into the red either laterally or vertically, but more frequently there is a sharp erosional break. This is almost invariably true where the graywacke overlies red shales or even dark shales. A layer of intraformational conglomerate may then occur at the base of the grit.

Laterally the beds change rapidly along both strike and dip with a general coarsening eastward. All reports have shown coarse sands and conglomerates in the east changing to red shales in the west, and this applies to Pennsylvania as well as to New York. The red beds grade into their marine equivalents in the west. This is a true gradation with interfingering of marine and nonmarine zones.

It is also notable that the base of the red beds rises westward, as does the thick graywacke zone. Thus the Kiskatom red bed zone at the eastern Catskill front is Hamilton in age, while at Johnstown, Pennsylvania, the earliest red beds are Upper Chemung. There can be no doubt

that the Catskill sediments were derived from the east and were pushed farther to the west into the sea as time went on both by the ordinary processes of sedimentation and the rise of the eastern landmass from which the deposits were being eroded.

MINERALOGY

Graywackes and associated conglomerates.—The mineralogy of the graywackes and associated conglomerates hardly changes throughout the area. Quartz, in some specimens, makes up more than 80 per cent of the rock. The quartz grains show various characteristics, some of which are extremely important in demonstrating the origin of the sediments. In a few thin sections, some of the quartz is clear, but almost always it is full of inclusions. Liquid and irregular inclusions (Pl. 2, fig. 1) are common and may indicate an igneous or vein origin. Crystalline inclusions are less common and are generally too small to identify. Of the larger crystals, apatite, rutile, and a brown tourmaline again suggest an igneous (perhaps pegmatitic) origin. Chlorite inclusions are, however, more abundant, and most significant of all is the altered mica—vermiculite—which occurs in practically every section. This points definitely to a vein origin. In addition, some of the larger grains are intergrown and elongated, a texture that can be associated only with vein quartz. The most prevalent type of inclusion is one in which very small dark dot-like masses are scattered throughout the grain, some aligned in an irregular criss-cross pattern.

Much of the quartz shows evidence of having been derived from a metamorphic source. Undulatory extinction is common, and the beginnings of fracturing and slicing (Pl. 2, fig. 4) may be seen in many grains. Such features do not indicate a very high degree of metamorphism, and it is possible that some of these effects were subsequent to deposition. Nevertheless, the fact that such quartz occurs throughout the area and in beds that could scarcely have been affected by metamorphism points strongly to a pre-depositional origin of the strain effects. Undoubted evidence of a metamorphic source is shown by quartz with recemented fractures and more particularly by grains showing regrowth before deposition (Pl. 2, fig. 2). These latter consist of one or more quartz grains some of which show a well-rounded original grain outlined by small dark inclusions with secondary quartz surrounding them. As this secondary quartz has no relation to the texture of the present rock but fills in the texture of the source rock grain, the regrowth must have taken place prior to the breaking down of the source rock.

The presence of secondary post-depositional quartz is indicated by the silicification of the groundmass, the regrowth of a few of the larger

grains in rare instances, and the ragged edges of some of the grains. That the majority of the larger grains were not too seriously affected is shown by the continuation of original inclusions to the boundaries of most of the original grains.

A few grains of plagioclase are present in nearly every section. The composition varies somewhat but is in the sodic range. In a few cases, plagioclase occurs in the groundmass in small unaltered grains. Otherwise the grains are large (although smaller than associated quartz grains) and unrounded when fresh. In most sections the plagioclase is altered, usually to sericite, or replaced by calcite.

Orthoclase is less common than plagioclase, probably because it alters more readily. The grains are unrounded and smaller than the associated quartz. It is almost invariably altered to sericite and carbonate.

Microcline, as a single party altered grain, was found in a single section.

Aside from quartz, biotite was probably the most abundant detrital mineral. At present, only in one section is there a grain of biotite, but altered mica makes up a high percentage of the detrital grains. One type of altered mica shows green to brown pleochroism, high birefringence, and a zero-degree axial angle. This mica, which most closely resembles the biotite from which it was derived, is relatively rare. More frequently, the altered mica, while highly birefringent, lacks color and clearness because of alteration and is contorted and bent around the quartz grains with which it is in contact (Pl. 1, fig. 1; Pl. 2, figs. 3 and 5). In other cases, the biotite has altered to such a degree that only mica lamellae filled with dark, earthy alteration products remain (Pl. 2, fig. 5). In some, green pleochroic chlorite is the end product, and one chlorite grain was seen which had oriented rutile intergrowths in a trigonal pattern, strongly suggesting its origin from biotite.

Colorless mica resembling muscovite is rare but is present as a few large, somewhat altered grains.

Calcite is widespread in the rocks and seems to be both primary and introduced. It occurs most frequently in the groundmass but also is present as grains of fine-grained carbonate. Some of these are large in the more conglomeratic phases but usually they are small. In some of the shale conglomerates, the shale pieces are very rich in carbonate and suggest that the waters from which the sediments were deposited were high in lime. The relative amounts of primary and introduced calcite could not be determined.

Among the heavy minerals, zircon, ilmenite, tourmaline, garnet, and magnetite are present in very minor amounts. The zircon is colorless, seldom rounded, and shows the typical pyramid and prism. Ilmenite, partly altered to leucoxene, is in shapeless grains. A few grains of un-

rounded tourmaline were seen. One variety is dark brown with a muddy green-brown to almost black pleochroism. Another is dark blue green to colorless. A third has pleochroism of colorless to dirty green brown, while one is blue with the terminated end brown. A light-colored garnet and magnetite are very rare.

In addition to the individual minerals, definite rock grains occur such as quartzite, hornfels, granulite, slate, phyllite, and vein quartz. One of the most striking types of grains in the graywackes is made up of small interlocking quartz grains. A miscroscopic examination of a few quartzite pebbles in one of the conglomeratic layers revealed an identical texture. The quartz grains showing regrowth also come from a quartzite in all probability. A granulite, consisting of a quartz aggregate with oriented chlorite, occasionally is present. Many small shale fragments, green, red, and black, are visible.

The pebbles and large fragments resemble the rock grains in composition. The large, well-rounded pebbles are of vein quartz, quartzite, or fine-grained crystalline metamorphic rock. The quartzite pebbles frequently have quartz veins within them and range from black to white; some are banded. A greenish-black metamorphosed argillite pebble, rich in chlorite, contains veins of quartz and chlorite. The fragments of softer rocks are angular. Red, green, and black shale fragments are abundant, and some make up the intraformational conglomerates. Their usual occurrence is as long, relatively narrow fragments parallel to the bedding.

The matrix consists essentially of fine-grained detrital angular quartz, sericite, and altered mica, with carbonate locally abundant. Much of the carbonate was introduced after deposition, but some undoubtedly was primary. Chlorite makes up a small percentage of the groundmass in some sections, and where the rock has been weathered hematite and limonite may coat the grains. Rarely, a grain or two of fresh plagioclase is present in the groundmass. It is possible that both plagioclase and orthoclase were originally more abundant in the matrix but were later altered to sericite. Later silicification in some of the specimens has resulted in an interlocking of the matrix grains and a strengthening of the texture of the rock.

The chief alteration products are hematite, limonite, sericite, chlorite, altered mica, and leucoxene. Hematite occurs both in grains and as a cement outlining the grain boundaries in weathered specimens of the rock. It also stains the edges of grains and surrounds small masses of carbonate. Pyrite edges are weathered to hematite, and some of the iron oxide is concentrated along open fractures in the weathered rock. Some limonite is present in the groundmass. Sericite has resulted from

the alteration of the feldspars and possibly some of the original mica. Original ferromagnesian minerals, including biotite, are responsible for most of the chlorite present, although it is possible that even some of the chlorite may be detrital. The chlorite occurs in grains as well as in the groundmass. The characteristics of the contorted and altered mica were cited in the discussion of primary biotite. These micas now make up over 25 per cent of some of the rocks. Leucoxene denotes the presence of original detrital ilmenite.

There is evidence that after deposition and probably after consolidation, low-temperature solutions deposited pyrite, galena, and calcite in the rocks. Both the pyrite and galena seem to be related to the organic matter in the graywackes for they occur either replacing the carbonaceous material or associated with it. The pyrite is in perfect cubic crystals with sharp crystal boundaries. Some weathering of the pyrite edges to hematite has not changed their sharpness. The galena is present in very small quantity, only on Mt. Utsayantha, near Stamford. With pyrite, it replaces carbonized plant remains. Calcite, identified by its cleavage, twinning, and reaction to hydrochloric acid, replaces quartz and feldspar (Pl. 2, fig. 6) and also is an introduced cementing material. As a secondary mineral it is well crystallized and with good boundaries where it replaces quartz. One specimen shows a microscopic vein of calcite.

Silicification is also apparent in some of the specimens, particularly in the groundmass. This silicification was prior to the introduction of the calcite, for calcite replaces the silicified grains in a number of instances.

Red sediments.—The mineralogy of the red beds is not essentially different from that of the graywackes except that the composition is somewhat simpler, but the grains are smaller and slightly rounded, and the mica well oriented along the bedding. The quartz is somewhat clearer than in the graywackes, but the vermiculite inclusions persist, and grains of fine-grained quartzite in addition to quartz with undulatory extinction and recemented fractures indicate a complex history for the source rock. Even in these red sediments a few grains of plagioclase persist but they are rare. Contorted grains of altered mica (biotite?) are common, and chlorite and sericite are present. Of course, the mineral showing great increase over its proportion in the gray sandstone is hematite, which occurs both in small aggregates and as a heavy coating and cement around the grains.

COLOR OF THE SEDIMENTS

The graywackes and their associated conglomerates vary from light gray to dark gray and from greenish to bluish. The greener phases

show a high chlorite content and sometimes an increase in small green shale fragments. The light-gray sandstones are usually rich in calcite, while the dark-gray rocks are commonly finer-grained and somewhat weathered. The blue sandstones seem to be purest and hardest with the color possibly due to the combination of quartz, dark shale fragments, carbonaceous matter, and altered biotite. The red beds vary from bright red to chocolate-colored with only some of the fine-grained shales attaining true red. A thick cement of hematite is responsible for the coloration of these beds.

TEXTURES

Angularity.—The grains of the graywackes are extremely angular and show no evidence of having been rounded. While Berkey (1907-1908, p. 154; 1911, p. 120) claimed that regrowth of quartz has made somewhat rounded grains more angular, grains showing no regrowth are also angular, and the plagioclase and orthoclase grains do not show rounding. Moreover, in the red sandstones, where there is no evidence of later silicification, the grains are likewise angular although not quite so sharp as in the graywackes. Although the pebbles of the conglomerates are well rounded, the grains of the matrix are angular and resemble those of the graywackes.

Size, sorting, and variation.—In no specimen of the graywackes, except where it approaches a shale, is the grain size uniform, and usually the variation is extreme, ranging from pebbles in the conglomerates or large sand grains in the coarse graywackes to very fine-grained quartz in the matrix material. The pebbles of the conglomerates do not usually exceed an inch in diameter. Locally, as at Jacob's Ladder at an elevation of approximately 2700 feet, the conglomerates become massive with pebbles as much as 4 inches long, but usually the conglomerates occur as streaks or thin layers in the gray sandstones. In the coarse- to medium-grained graywackes, the larger quartz grains may be half a millimeter in diameter or even slightly larger. There is no sorting, and the rock consists of a helter-skelter arrangement of large to small grains in a clay and fine sand matrix (Pl. 1, fig. 2). The whole effect is of suspended material dropped rapidly and fairly completely. Only in the finest-grained gray material is any homogeneity of grain size apparent, and even here the sorting is rather poor.

In the red sandstones the case is somewhat different, however. The grain size varies but little, and the microscopic appearance of the rock is much more uniform and even-grained (Pl. 1, figs. 4 and 5). The grain diameter averages slightly more than a tenth of a millimeter in the coarser red sandstones, and the sorting is good. When these facts,

coupled with the slight rounding of the grains, are compared with those for the graywackes, there seems no doubt but that the red beds were transported farther from the source of the sediments than the gray sandstones and that they were deposited more slowly.

SEDIMENTARY STRUCTURES

Bedding.—The thinnest bedding occurs in the shales, and the thickest in the conglomerates. The red and green shales break into laminae as thin as a quarter of an inch, and the bedding is well developed and regular. A good orientation of weathered mica seems to be responsible, at least in part, for these characteristics of the red shales. The red sandstones are generally well bedded although there are exceptions. The beds average about an inch thick, and the sandstone breaks into slabs. In the graywackes that have been quarried for flagstone the bedding varies from about 1 inch to over 6 inches, and the rock is exceedingly well bedded and breaks out in large blocks that may be a number of feet square and a few inches thick. Generally the thickness of the beds does not vary for neighboring beds. A number of adjacent beds have about the same thickness, and then abruptly the overlying or underlying strata will show a marked difference.

The coarser graywackes are more massive, and the bedding less perfect. Finally, in the conglomerates, the thickness of the beds increases greatly, and in most cases no bedding is visible.

Cross-bedding.—As already pointed out, cross-bedding is characteristic of the graywacke. Each layer of the cross-beds is cut off above at a low angle (maximum 25°) by dipping beds. The cross-beds are usually straight but occasionally are slightly curved. These cross-beds are due to the deposition of sediment by fast streams on an alluvial fan. The conglomerates frequently show cross-bedding, and rarely dark shales are cross-bedded with the sandstones. The red beds are seldom cross-bedded and when they are it is on a very minute scale, the laminae being no more than a few millimeters. The laminae are also curved.

Banding.—The graywackes may show banding occasionally. Black layers alternate with thicker light-gray layers. Only in an exceptional case do the black bands exceed a millimeter, while the lighter laminae range from three to five times as thick as the associated dark material. The dark coloration of the bands seems to be due to a concentration of oriented altered mica, and this implies an original concentration of biotite aligned in bands parallel to the bedding. The banding is more frequent in the finer-grained rocks than in the coarser and may represent a time when the stream depositing the sand was moving very slowly.

Whatever caused the banding was periodic for the bands are regularly repeated throughout the rocks in which they are present.

Ripple marking.—While ripple marking occurs in both gray and red sediments, it is very rare in the former. It was only at two localities—an abandoned quarry at Hawk Mountain between Fish's Eddy and Cadosia and along Ouleout Creek just below the broken dam at East Sidney—that ripple marks were seen in the graywacke. These are cross ripples and suggest a shore environment, but whether fresh water or marine can only be conjectured. As the slabs on which the ripple marks were visible at the quarry were not in place, the relationships of these specimens with the surrounding rock could not be studied. The Ouleout Creek occurrence is near the location of a wedge of marine fossiliferous strata discovered by J. M. Way and described by Jewett (1862, p. 418), Hall (1861, p. 377-381), and Darton (1893, p. 203-209) as Chemung and by Chadwick (1936, p. 69) as Enfield separating the Onteora beds from the Katsberg and being early Katsberg in age. It is conceivable that this cross-rippled sandstone, therefore, was laid down along a marine shore; while such an environment is somewhat at variance with the usual locale of the graywacke, it is entirely probable that a very small proportion of the gray beds was deposited close to a marine environment.

Ripple marking in the red beds is more common. The red shales sometimes show current ripples. Cross ripples (Crow's-nest type) are also found in the red sandstones.

Mud cracking.—Mud cracking occurs in the red shales and gives direct evidence that they were exposed to the atmosphere. At Bragg Hollow near Halcottsville, there occurs a mud-cracked layer, and the bed just above is ripple marked. Such structures strongly suggest that the red shales were deposits on a flood plain or on the subaerial topset part of a delta.

Intraformational conglomerates.—An important feature in the history of the sediments is the presence of conglomerates that appear to be of an intraformational character. The matrix material corresponds exactly with the graywackes, while the large fragments are angular pieces of shale, usually dark but sometimes red. These conglomerates most frequently occur as the basal beds of a graywacke series above shale beds and indicate erosion of shale beds deposited a short time before. Renewed uplift or a shifting of the stream course might have been responsible for the formation of these conglomerates.

Tube-like structures.—In the red shales, there occur long tube-like impressions filled with fine clay and usually covered with a shiny surface.

They branch irregularly and in some cases show faint longitudinal groovings. The maximum diameter of the tubes is about 2 centimeters, but the average cross section would measure much less than this. The tubes are never straight and cut across the bedding. They may represent weak, hollow, reed-like plants growing on a river flood plain or delta.

PALEONTOLOGY

Animal fossils are extremely rare in the Catskill deposits and suggest a fluviatile origin. For a long time the fresh-water habitat of *Amnigenia catskillensis* has been recognized. *Stylonurus lacoanus* (*S. excelsior*) from the Catskill sandstone at Andes was described by Hall (1883). A fresh-water environment for many eurypterid genera is gradually being accepted. The fish of the Catskill facies are all from primitive groups for which a brackish-water habitat was postulated by older paleoichthyologists, such as Newberry (1889), and a fresh-water environment suggested by more recent workers as Romer and Grove (1935). Eastman (1907, p. 22) gives the following list of fish from the Catskill beds: *Bothriolepis nitida, B. minor, Onchus rectus, Gyracanthus sherwoodi, Dinichthys* sp., *Holonema rugosum, Dipterus angustus, D. contraversus, D. fleischeri, D. sherwoodi, Ganorhynchus beecheri, Holoptychius americanus, H. giganteus, H. halli, H. radiatus, Sauripteris taylori,* and *Glyptopomus sayrei.* To these genera might be added *Coccosteus* and *Acanthaspis.* These forms, which include placoderms, lungfish, and crossopterygians, occur sparingly in the sandstones and favor fresh-water depositional conditions.

The only other organic remains in the Catskill beds are of plant origin and may be abundant along certain horizons. Aside from the trees of the fossil forest at Gilboa and the doubtful plant tubes in the red shales, the plant fragments lie along the bedding and indicate that they were transported before deposition. The plants were all land-dwelling forms such as *Eospermatopteris, Archeopteris, Protolepidodendron,* and *Psilophyton.*

All the fossils present in the Catskill facies are, therefore, in accord with a fresh-water environment and indicate strongly that this environment was a fluviatile one.

SECONDARY EFFECTS; WEATHERING

As previously pointed out, the Catskill area was only slightly affected by the Appalachian orogeny. Along the eastern front the Catskill beds have a westward dip, but the strata are more nearly horizontal a short distance to the west although there are a series of very gentle northeast-southwest striking folds throughout the area. The only possible evidence

of dynamic metamorphism in the rocks themselves is the sliced and fractured character of some of the larger quartz grains of the coarse sandstones where the large grains may have acted as ball-bearings and taken all the shock of the movement. There is the possibility, however, that many of these grains were deformed prior to deposition. Petrofabric analyses of three specimens revealed no alignment of the quartz, and the conclusion reached was that no forces strong enough to orient even partially the grains in the graywackes had acted on the rocks.

That solutions passed through the rocks after formation is evidenced by the introduced pyrite, galena, and calcite, and by silicification of the groundmass. The pyrite most frequently is concentrated along carbonaceous layers in the graywackes, and it and galena replace carbonized plant remains. The calcite, some of which is primary and detrital, acts as a cement and may reach a high percentage in some of the graywackes. Many specimens of quartz and feldspar are partially replaced by calcite, and probably more are so completely replaced that all vestiges of the original minerals are lost.

Previous to the passage of the sulfide-bearing solutions, the plant fragments were carbonized, for all the vegetable material in the sediments is now in the form of coal. Loss of volatiles and concentration of carbon could only have been due to load metamorphism, as it has been shown that dynamic movements played no essential part in the history of the rocks.

The weathering of the rocks presents many interesting problems, but more study is needed. The red shales usually break into small fragments or chips of dull and soft appearance. Ultimately they weather into a fine red clay which sifts down over all the rocks and discolors them. The graywackes weather with the alteration of the ferro-magnesian minerals, such as biotite, producing iron oxides which in many cases color the rock brown, thereby making it often hard to distinguish from the red sandstones; the only clue to their origin is in the texture and structure of the rock. There have been cases where the gray sandstone appears to have weathered through a red sandstone stage to what looks like a red shale. At Deposit in a large abandoned quarry in the gray sandstone, a red shale or sandstone layer is present as a broken bed in the graywacke, and as it is followed along the face of the quarry it disappears into solid gray sandstone. Some of the loose pieces of the red rock on the quarry floor show structures identical with those of the graywacke. This would seem to be an instance of the graywacke weathering to the red shale.

Under other conditions, and particularly in the case of some of the conglomerates which are quite porous, calcite and dark coloring ma-

terials are removed so that a very light colored rock results. Commonly, these constituents are removed, and hematite is precipitated with a resulting light-red, weathered-looking conglomerate as a product.

CONDITIONS AFFECTING SEDIMENTATION

GENERAL STATEMENT

An attempt has been made to present the facts bearing on Catskill sedimentation and to avoid, as much as possible, any theorizing as to the cause of the character of the deposits. The remainder of this paper will be devoted to a discussion of inferences and conclusions based on the facts presented.

SOURCE OF MATERIALS

Barrell (1913; 1914) claimed, on the basis of the large, well-rounded quartzose pebbles of the conglomerates, that the Catskill sediments were derived from pre-Cambrian crystalline rocks which he located "at least as far as eastern Connecticut and the region now overlain by the strata of the Coastal Plain". He disregarded the nature of the graywackes as a key to the source of the deposits and also the fact that, in the conglomerates interbedded with the graywackes, the pebbles were frequently fine-grained quartzite, hornfels, or granulite and that gneissic or granitic pebbles were absent.

In the author's opinion, all facts tend to indicate a fairly close source of derivation *i. e.*, one within 50 to 75 miles of the present eastern limits of the deposits. The extreme angularity of the grains points definitely to a near-by source. No grains in the graywackes, no matter how large, show evidence of rounding, and it is inconceivable for such material to have been transported very far. The cross-bedding of the graywackes also implies a not distant source. The cross-bedding is due to stream deposition of a torrential type on interfingering alluvial fans. The most perfect environment for such conditions would be at the foot of mountains where rapidly moving streams debouch upon a plain. The prevalence and fine development of the cross-bedding in the gray deposits point very strongly to such an environment for the gray beds.

The unsorted character and helter-skelter arrangement of the grains of the graywackes strongly backs the assumptions made on the basis of the cross-bedding. Rapid dumping of stream-carried material is suggested, and the best place for such an action is on an alluvial fan at the foot of the mountain from which the sediments are being derived. The intraformational conglomerates also imply somewhat similar conditions. The breaking up of a partly consolidated clay layer and redepositition at the base of a sandstone requires a rapidly moving current. The farther

along the stream course from its source that one goes, the less likely is the chance for a suitable environment for the production of such conglomerates.

The uppermost Catskill beds in New York are more conglomeratic than the lower. The pebbles are large and, as at Jacob's Ladder, near North Lake, may average 4 or 5 inches in diameter. Barrell realized the difficulty of moving such large pebbles great distances, for in the case of the Skunnemunk conglomerate (which he placed nearer to his source than the Catskill beds) he (Barrell, 1914, p. 246) stated:

> "Furthermore the coarseness of the quartzite boulders in the Skunnemunk conglomerate is such that rivers probably did not carry them from the mountains more than 75 or 100 miles."

The Skunnemunk conglomerate does not differ appreciably from some of the more massive Catskill conglomerates. It might be pointed out that, while the conglomerates were deposited close to the base of the mountains, it does not necessarily follow that the graywackes were, too. Although the graywackes may have been deposited slightly farther away from the source, the angularity of the grains and the poor sorting of the materials show that this distance could not have been great. Moreover, in the Siwalik deposits of India, which may be analogous to the Catskill deposits, the upper conglomerates are of local origin at the emergence of mountain streams (Wadia, 1919, p. 237) and a similar case might be made out for the Catskill conglomerates. It is the author's opinion that the increased coarseness of the upper beds denotes a heightening of the mountains from which the deposits came with only a slight change in distance from the source.

Another indication of the nearness of the source beds is the position and nature of plant fragments in the graywackes. With the exception of the Gilboa trees, all the plant fragments lie parallel to the bedding, showing that they are not in place. Some of these remains are several feet long; in others, leaf structures are preserved. The inference is, therefore, transportation for only a short distance.

The most direct evidence for the source is the composition of the grains and pebbles of the sandstones and conglomerates. The metamorphic character of these materials has been stressed, and only certain significant features will be reconsidered. Many of the quartz grains show a derivation from a quartzite, and others, by their undulatory extinction and fracturing, show that in their previous history they underwent the effects of pressure. The presence in abundance in the pebbles, or the grains, of fine-grained quartzite, granulite, hornfels, slate, phyllite, shale, and fine-grained limestone suggests that the region from which the Catskill sediments came was one of early Paleozoic metamorphic and

sedimentary rocks. The great abundance of what was originally detrital biotite substantiates this. The presence of plagioclase and more rarely of orthoclase does not conflict with such a source.

The high percentage of quartz of vein origin might, at first sight, appear at odds with the contention just proposed. However, the metamorphosed early Paleozoic rocks of the Taconic region (whence the Catskill sediments of New York were in all probability derived) are greatly cut by and injected with quartzose material and pegmatites. The presence of pebbles containing quartz veins in the Catskill beds suggests that the vein quartz material comes from veins cutting the metamorphic rocks listed.

The rounded character and quartzose composition of the larger Catskill pebbles was a strong argument of Barrell's in favor of a distant source. Here again an analogous situation with the Siwalik of India shows that the conglomerates there contain rounded boulders of the harder rocks of the Himalayan chain (Oldham, 1893). Medlicott (1864) characterizes the material of the Siwalik conglomerates as

> "an admixture of the same boulders as are now only to be seen in the beds of the great mountain torrents, a schistose quartzite being the prevailing variety, with a greater or less amount of the débris and of other rocks derived from the Masuri ridge."

These schistose quartzite pebbles are well waterworn. When it is remembered that these conglomerates occur within 50 miles of the base of the Himalayas, it can be seen that neither the rounding nor the composition of the pebbles is proof of their having been transported long distances beyond the base of the mountains.

Barrell chose the southeast as the chief source of the Catskill beds; he pictured the mountains as crossing northern New Jersey with the foothills approximating the position of the present Fall Line. However, it has been established that the earliest Catskill deposits (Ashokan and Kiskatom) in New York occur in the northeasternmost area of the Catskill region, and the deposits become progressively younger to the south and west (disregarding the Skunnemunk outlier for the moment). Such an arrangement seems to indicate that highlands existed to the north and east of the Catskill region and were responsible for the New York Catskill sediments.

A derivation of the rocks from the northeast and east is favored by the work of Sheldon (1929, p. 532) on the Portage sandstone at the head of Cayuga Lake. According to the older classification the Portage is the marine equivalent of the Oneonta beds, while Chadwick (1935, p. 343-354) places the Portage above any of the New York Catskill rocks. Even so, the direction from which the Portage beds came implies highlands

to the northeast and east during Upper Devonian times, and there is no reason to suppose that similar beds earlier in the Devonian did not have a similar origin.

All these facts seem to point to the conclusion that the New York Catskill deposits were derived from a near-by source of metamorphic and sedimentary Paleozoic rocks which lay to the east and north of the present Catskill area. The complex of metamorphosed sediments with intrusions of pegmatite and vein quartz (which were, without doubt, capped by limestones and shales in Silurian and early Devonian times) known as the Taconic system fits the description perfectly. The rocks of the Taconic-Berkshire-Green Mountain belt occur in westernmost New England (Fig. 1) where today they rise above the general level because of the greater resistance of their crystalline rocks—chlorite and albite schists, marbles, quartzites, and slates. That the zone in which they lie was unstable throughout the Paleozoic is well known, but that these lands were high during the Devonian has not been definitely proved. These Taconic rocks have, from time to time, been suggested as the source for the Catskill gravels, sands, and clays, but the author knows of no conclusive proof advanced for this. It is hoped that the present paper will remove any doubts as to the verity of this point.

Although the northeast and east were the important sources for the Catskill beds, some material probably came from the southeast, and in Pennsylvania and Maryland the east and southeast seem to have been the places whence the major part of the sediments were derived. A change of trend of the Devonian highland front is also indicated with the north-south Taconic direction changing to a southwest strike of the strata.

MODE OF TRANSPORTATION

It has already been shown that the gray sediments are of the type deposited by torrential streams where they form an alluvial fan at the foot of the highlands. The red beds, on the other hand, represent material that was carried beyond the alluvial fan and deposited along the course of the stream or on the delta near where the stream entered the sea. There were no major rivers with tributaries, but many small straight streams drained the highlands and flowed rapidly out to sea depositing their load on alluvial plain, flood plain, or delta. While the climate was probably not arid, the cross-bedding and banding of the gray sandstones suggest that rainfall was somewhat seasonal and that the streams were greatly reduced in size and carrying power part of the time.

METHOD AND PLACE OF DEPOSITION

Sand, gravel, and clay were carried in suspension by these rapidly moving streams, and as they emerged at the base of the highlands a large proportion of the load was dropped because of change of velocity. The quickly deposited material was very poorly sorted and extremely angular except for the large pebbles which came from within the highlands. A mass of pebbles, large to minute quartz grains, flakes of biotite and perhaps of chlorite, some small fragments of limestone, shale, quartzite, slate, and schist was left mixed with clay, plant fragments from the highland slopes, and a few grains of feldspar and other minerals that occurred in the source rocks. Such a bed would remain exposed to the atmosphere for only a short period before another time of rapid stream flow would ensue. The tops of the newly formed beds might be eroded before more material was dumped, and in this way cross-bedding would result. The alluvial fan deposits would thus be built out by each successive time of deposition, until their margins would coalesce with the neighboring fan materials and an alluvial plain would be formed. This alluvial plain would push still farther from the front of the highlands until a great area of sandy deposits would lie between the highlands and the sea. Rarely, however, would the sea lap up onto these deposits, for separating the sandy plain of coarse cross-bedded material from the sea was a flood plain and delta built up of the finer sediments not initially dropped by the streams. Thus the sandy deposits would grade into finer sands, with grains slightly rounded and better sorted, indicating slower deposition. This slower rate of deposition would mean that the finer-grained material could be acted upon by the processes of oxidation for a longer period of time than the coarser deposits, and hence the finer sandstones are lighter or red. In their turn, the fine sands graded into clays which were exposed on the flood plain farther downstream and also on the topmost portion of the delta, which might be considered a continuation of the flood plain. The red color and mud cracking of these shales show that they were exposed to the atmosphere a good part of the year. Massive conglomerates close to the foot of the highlands gave way to cross-bedded conglomerates and graywackes which extended as an alluvial plain for perhaps 100 miles beyond the highlands. These graded into finer-grained, better-sorted sands on the flood plain, and these into shales which finally interfingered with marine beds on the delta.

The dark-gray or greenish shales that occur locally as lenses in the graywackes might be interpreted as lake deposits or fine-grained deposits laid down when the stream velocity was decreased.

That the sea sometimes reached as far inland as the alluvial plain or flood plain is denoted by the cross ripples in the graywacke and red sandstone, but these occurrences were very rare and probably local. The area upon which all these deposits were being laid down was not one of stability but was sinking slowly as shown by the 4000 feet minimum thickness of the Catskill beds and the great thickness of marine beds beyond the delta.

CLIMATE

While the presence of red beds is often considered to indicate arid or semi-arid conditions, the dark color of the graywackes and the abundance of plant remains in them points to moist conditions, at least during part of the year. Two causes might be held responsible for the formation of the red beds. Their slow deposition on a flood plain or subaerial delta surface would mean longer exposure to the atmosphere and their position as low-lying lands behind the Devonian highland would prevent them from receiving much of the precipitation of the moisture-laden winds. Thus, though the normal climate might well have been similar to what it is today in the Catskill region, the area where the finer sands and clays of the Catskill facies were being deposited would have the semblance of semi-aridity.

However, there is basis for assuming a semi-arid condition for a short period in the Late Devonian. This was during the time of deposition of the red-matrixed conglomerates of some of the higher Catskill slopes. The red color might be due to later weathering of gray rocks or it might be primary. In the former case, no change in the original conditions is, of course, necessary. If the latter assumption is true, then a semi-arid climate must be postulated to account for the red conglomerates. Such a climate would have been temporary.

INDICATIONS OF UPLIFT OF DEVONIAN HIGHLANDS

A general consideration of the Catskill deposits shows them to be typical "flysch" deposits—*i. e.*, deposits formed during the rise of a landmass. The earliest deposits (Ashokan) are fine-grained graywackes and are fairly uniform and homogeneous. They denote the earliest rise of the Taconic area in the Devonian. The uniformity and fine grain of the Ashokan beds may denote either of two things with regard to the Devonian highland. The early uplifting movements may have been very gentle, or the uplifts may have begun farther to the east and progressed inland during the Middle and Late Devonian. The Kiskatom beds with their high percentage of red shales and sandstones indicate that the Devonian highlands were still not very high, but the increasing coarseness and occasional conglomerates of the Upper Kiskatom show that the

Taconic area was still rising and that the zone of orogeny might be moving westward. Orogeny increased throughout Onteora and Katsberg times, for the highest deposits are the coarsest and most massive and cover a greater area than the earlier sediments. The Catskill beds, as a whole, convey clearly the picture of an orogeny of not very great intensity beginning early in Hamilton time and slowly moving eastward and gradually increasing slightly in intensity throughout the Middle and Upper Devonian with the maximum development in the late Upper Devonian and probably after the highest of the present New York Catskill beds had been laid down.

This does not mean that the rise of the mountains was steady, uniform, or continuous. A rise of the Taconic belt might be followed by a long period of stability and erosion. Then another movement would occur renewing the stream velocities and coarse deposits. The second movement might be more or less intense than the first. It is only when the large-scale aspects are studied that the generalization of increased intensity of movement is valid.

SUMMARY OF CONDITIONS OF SEDIMENTATION

During the Lower and early Middle Devonian the Catskill area was beneath the sea, for marine deposits of those ages are now found there. Schuchert and Longwell (1932, p. 321-322) conceive of this seaway as following the Hudson Valley north from the Catskill region to Montreal and thence down the St. Lawrence Geosyncline to Gaspé and Newfoundland. They think that the Bernardston deposits (which they claim are late Lower Devonian in age) may once have connected across the eroded Taconic Mountains with the beds of the Hudson Valley and with the Lower Devonian deposits of northern New Hampshire and Gaspé. Uplift began in Gaspé in the late Lower Devonian but did not reach the Massachusetts and Connecticut Taconic area until early Hamilton times. The early uplifts were not very great but were enough to produce rapidly moving youthful streams which built up coalescing alluvial fans of medium coarse sands. The sea which was originally close to the foot of the mountains was pushed back, and gradually an alluvial plain of coarse cross-bedded sands was formed grading into a flood plain with fine, fairly well sorted sands and clays which passed into the topset beds of a delta. As time went on many variations in the height of the mountains and the amount of rainfall took place, but, in general, there was an increase in the height of the mountains and an increase in the size of the materials carried by the streams. The mountains were well wooded with ferns, large clubmosses and equisetes, seed ferns, and primitive spermatophytes, and frequently the fragments would be carried down

and mixed with the alluvial deposits. The streams carrying the rock materials would drop much of their load on emerging upon the plain at the base of the mountains. Well-rounded pebbles from deep within the mountains, coarse and fine angular sand, and pebbles, clay, and pieces of wood would be mingled together in a haphazard manner. Only the finer sand and clay would be carried farther by the stream and slowly deposited along its course or on its delta. The finer deposits would be exposed to the atmosphere for relatively long periods and would acquire a cement of iron oxide. As the rainfall was somewhat seasonal, a short period of nondeposition might be followed by another rapid flow of waters. The upper parts of the earlier-deposited beds might be eroded and new deposits dropped on their edges, causing the strata to be cross-bedded. At times of unusual flow due either to renewed uplift of the highlands or increased precipitation, some of the clay beds might be torn up and their fragments strewn with the newly deposited coarse sands forming an intraformational conglomerate. At other times decreased stream flow might result in red clays. A great alluvial plain of sand was gradually built out from the base of the mountains and extended for more than 50 miles to the west. This plain graded imperceptibly into a flood plain of finer materials which passed into subaerial topset delta beds exposed for long periods to the atmosphere. The mountains reached their maximum height in the latest Devonian, but deposits later than early Upper Devonian have all been removed by erosion from the New York area. The alluvial-plain deposits formerly extended beyond their present eastern limits and lapped up on to the Taconic belt from which they were derived. How far north the plain extended is a matter of conjecture, but Schuchert and Longwell (1932, p. 321) are of the opinion that the Catskill deposits reached as far north as Quebec.

If these be the true conditions under which the Catskill beds were laid down, it would seem that the term "alluvial plain" is more appropriate for the deposits than Barrell's term "subaerial delta." The word "delta" usually implies the deposition of stream-carried material in a standing body of water such as a lake or sea. In the Catskill sediments, most of the beds were deposited upon dry land on an alluvial fan, and only a small percentage of the shales were actually deposited as true deltaic material. Hence it is suggested that in the future the name "Catskill alluvial plain" be substituted for "Catskill delta."

PROBLEM OF THE SKUNNEMUNK CONGLOMERATE

There is no doubt that the Skunnemunk conglomerate is an outlier of Middle and Upper Devonian age as the beds overlie conformably the Hamilton Bellvale flags. This outlier is located next to Greenwood Lake on the New York-New Jersey boundary line and about 25 miles southeast

of the Catskill mass. Its occurrence can easily be explained as an extension of the Catskill sediments to the east with the connecting beds removed by erosion because of their position in the Appalachian thrust-faulted belt.

The probable origin for the Skunnemunk materials is in the crystalline rocks of the pre-Cambrian prong that passes through northern New Jersey and in which the Skunnemunk outlier is infolded and also in the Silurian conglomerates (Green Pond) of Medina-Oneida type. This would imply that the source rocks of the southern Catskill area were not the Taconic type of metamorphic rocks as in the case of the northern Catskill beds and that these died out toward the south. Probably a change in the trend of the Devonian landmass also took place with the north-south direction of the Taconic Mountain bending to the southwest as the New York-New Jersey line was approached.

Hence, the Skunnemunk deposits are interpreted as part of the Catskill facies and as being somewhat closer to the source which differed from that for the northern Catskill area. The coarseness of the Skunnemunk pebbles, the subangularity of part of them, and their composition favor such a conclusion.

PROBLEM OF DEVONIAN OROGENY

The assumptions made earlier in this paper necessitate a period of orogeny (Acadian) during the Middle and Upper Devonian in the Taconic area. The structural and stratigraphic evidence for such mountain building, while not direct, is strong. In Canada, it is well known that folding took place in the Devonian with movements beginning as early as the late Lower Devonian in Gaspé, and Clark (1934, p. 19) has concluded that the Acadian folding affected the southern Quebec area. Schuchert (1930; 1932) has long held the opinion that the Taconic Mountains were refolded in Acadian times with the Appalachian orogeny again affecting the southern part of the area.

Dr. Walter L. Whitehead, of the Massachusetts Institute of Technology, has been kind enough to suggest to the author the following interpretation of the structures present in the eastern New York-western New England area:

(1) The north-south striking structures are of Taconic (Ordovician) origin as claimed by Prindle and Knopf (1932) and Schuchert (1930, p. 710-718).

(2) These Taconic structures and thrusts were refolded and rethrust in the same direction in Acadian times. Prindle and Knopf show the complexity of the Taconic thrust belt. The long, major thrusts are folded and bent just as though they were rock strata undergoing folding. In places, the folding was so intense that new thrusts were developed cutting the Taconic thrusts and forcing some of the underlying rocks above the thrust-faulted rocks. The Rensselaer plateau is such a rethrust mass, its rocks probably being basal Cambrian of the Taconic sequence of Prindle and Knopf. Another similar thrust is present in the Taconic Mountain.

(3) Superimposed on part of these structures is a northeast-southwest trend due to movements in the Appalachian Revolution. The northeast-southwest structures are present in the Helderbergs and in a second cleavage developed in the Cambrian schists of the Taconic region. The double cleavage (one in the Taconic direction; the other in the Appalachian direction) dies out to the west at about the western limit of the Rensselaer block and its cessation may have some relation to movement of the block in Appalachian time. On Hoosac Mountain, in northwestern Massachusetts, there is some mullion structure showing movement from the southeast along a north-south trending thrust plane. This is interpreted as Appalachian movement along an old Taconic thrust.

This interpretation seems in accord with all the facts and explains particularly the complexity of the thrusts of the Taconic area. It appears impossible that the folding and thrusting of the primary thrust planes could have taken place in the same period of folding (Ordovician) in which the primary thrusts were developed. It also accounts for the folding in the Helderbergian limestones. The Appalachian movements were more intense in the south and died out toward the north. In the Catskill-Helderberg-Taconic area, much of the movement was taken up by the old Taconic and Acadian thrusts. The Helderbergian limestones which overlay some of the major thrusts were intensely affected by the movements, but only over a narrow belt. West of the thrusts the Appalachian folds rapidly died out so that the Catskill rocks show hardly any evidence of deformation. Ruedemann (1932, p. 340, 341) states that the Catskills lie

"in a broad synclinal trough, between the Adirondack uplift and its southern continuation and the Appalachian folds in the east and southeast with secondary anticlines running in the general direction of the Appalachian folding of the region."

A recent paper by Shaub (1938, p. 339-340) shows that the age of many of the New York and New England pegmatites may be Devonian, and some relationship between these pegmatites and an Acadian orogeny might be postulated. However, the validity of all the pegmatite ages might be questioned as the proportions of the lead isotopes were not determined. Nevertheless, the age determinations for the various pegmatites check each other and, hence, may represent true ages.

In this brief and sketchy summary of the tectonic history of the area, no more than an outline of the arguments in favor of a Devonian orogeny were given, but it is hoped that the necessity for three post-Cambrian movements has been demonstrated.

WORKS TO WHICH REFERENCE IS MADE

Barrell, Joseph (1906) *Relative geological importance of continental, littoral, and marine sedimentation,* Jour. Geol., vol. 14, p. 316-356; 430-457; 524-564.

——— (1913) *The Upper Devonian delta of the Appalachian geosyncline: pt. 1,* Am. Jour. Sci., 4th ser., vol. 36, p. 429-472.

Barrell, Joseph (1914) *The Upper Devonian delta of the Appalachian geosyncline: pts. 2 and 3,* Am. Jour. Sci., 4th ser., vol. 37, p. 87-109; 225-253.

Berkey, C. P. (1907-1908) *Quality of bluestone in the vicinity of the Ashokan Dam,* School Mines Quart., vol. 29, p. 148-158.

——— (1911) *Geology of New York City (Catskill) aqueduct,* N. Y. State Mus., Bull. 146.

Chadwick, G. H. (1933) *Catskill as a geologic name,* Am. Jour. Sci., 5th ser., vol. 26, p. 479-484.

——— (1935) *Chemung is Portage,* Geol. Sci. Am., Bull., vol. 46, p. 343-354.

——— (1936) *History and value of the name "Catskill" in geology,* N. Y. State Mus., Bull. 307.

Clark, T. H. (1934) *Structure and stratigraphy of southern Quebec,* Geol. Soc. Am., Bull., vol. 45, p. 1-20.

Darton, N. H. (1893) *The stratigraphic relations of the Oneonta and Chemung formations in east-central New York,* Am. Jour. Sci., 3d ser., vol. 45, p. 203-209.

Eastman, C. R. (1907) *Devonic fishes of the New York formations,* N. Y. State Mus., Mem. 10.

Hall, James (1861) *On the Catskill group of New York,* Canad. Nat., vol. 7, p. 377-381.

——— (1883) *Description of a new species of Stylonurus from the Catskill group,* N. Y. State Mus., 36th Ann. Rept., p. 76-77.

Jewet, Ezekiel (1862) Am. Jour. Sci., 2d ser., vol. 34, p. 418.

Longwell, C. R. (1933) *Eastern New York and Western New England,* 16th Intern. Geol. Congr., Guidebook 1, 1933.

Mather, W. W. (1840) *Fourth annual report of the first geological district of the State of New York,* N. Y. Geol. Survey, 4th Ann. Rept.

——— (1841) *Letter . . . relative to the geological survey of the State (of New York),* N. Y. Geol. Survey, 5th Ann. Rept.

——— (1843) *Geology of New York, Part I, comprising the geology of the first geological district,* Albany, N. Y.

Medlicott, H. B. (1864) *On the geological structure and relations of the southern portion of the Himalayan ranges, between the rivers Ganges and Ravee,* Geol. Soc. India, Mem., vol. 3, pt. 2.

Miller, W. J. (1924) *Geological history of New York State,* N. Y. State Mus., Bull. 255.

Newberry, J. S. (1889) *The Paleozoic fishes of North America,* U. S. Geol. Survey, Mon. 16.

Oldham, R. D. (1893) *Manual of the geology of India,* 2d ed.

Prindle, L. M., and Knopf, E. B. (1932) *Geology of the Taconic quadrangle,* Am. Jour. Sci., 5th ser., vol. 24, p. 257-302.

Romer, A. S., and Grove, B. H. (1935) *Environment of the early vertebrates,* Am. Mid. Nat., vol. 16, p. 805-862.

Ruedemann, Rudolf (1932) *Development of drainage of the Catskills,* Am. Jour. Sci., 5th ser., vol. 23, p. 337-349.

Schuchert, Charles (1930) *Orogenic times of the northern Appalachians,* Geol. Soc. Am., Bull., vol. 41, p. 701-724.

——— and Longwell, C. R. (1932) *Paleozoic deformations of the Hudson Valley region, N. Y.,* Am. Jour. Sci., 5th ser., vol. 23, p. 305-326.

Shaub, B. M. (1938) *The occurrence, crystal habit, and composition of the uraninite from the Ruggles Mine, near Grafton Center, New Hampshire,* Am. Mineral, vol. 23, p. 334-341.

Sheldon, P. G. (1929) *On the derivation of the Portage sandstones of central New York,* Am. Jour. Sci., 5th ser., vol. 17, p. 525-533.

Wadia, D. N. (1919) *Geology of India.*

Willard, Bradford (1933) *"Catskill" sedimentation in Pennsylvania,* Geol. Soc. Am., Bull., vol. 44, p. 495-515.

Williams, H. S. (1881) *The recurrence of faunas in the Devonian rocks of New York,* Am. Assoc. Adv. Sci., Pr., vol. 30, p. 186-191.

——— (1900) *Catskill formation sedimentation,* Geol. Soc. Am., Bull., vol. 11, p. 594-595.

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Explanation of Plates

PLATE 1—TEXTURE OF ROCKS

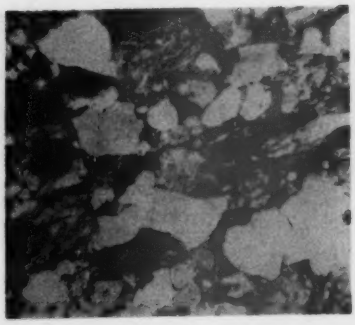
(1) Coarse graywacke showing angular quartz grains (white), grains of a metamorphic rock (gray), and contorted mica. Plane polarized light; x 35.

(2) Medium-grained graywacke with angular quartz, calcite, and sericite; crossed-nicols; x 35.

(3) Very fine-grained weathered graywacke; crossed-nicols; x 35.

(4) Fine-grained red sandstone; plane polarized light; x 35.

(5) Contact between red sandstone above and red shale below; plane polarized light; x 35.



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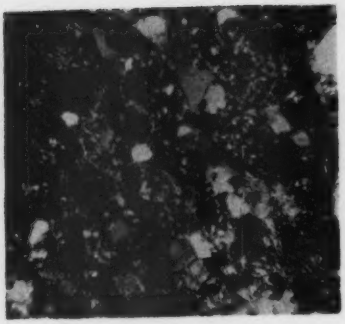

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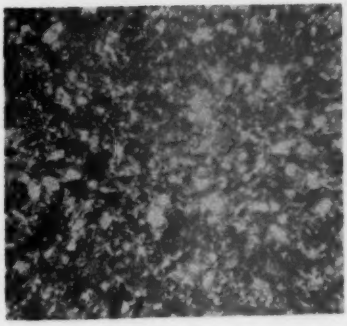

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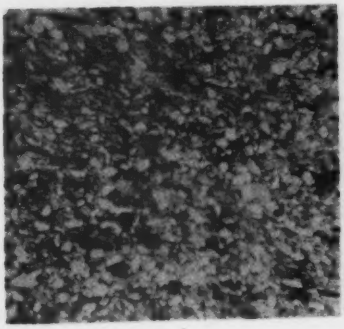

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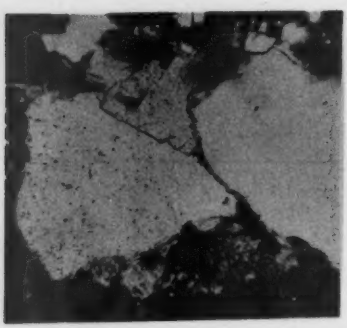
TEXTURE OF ROCKS



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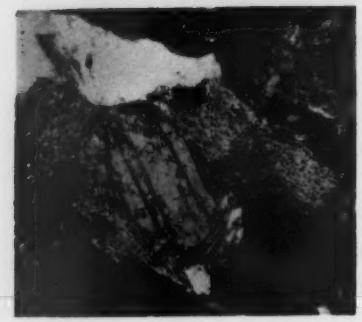

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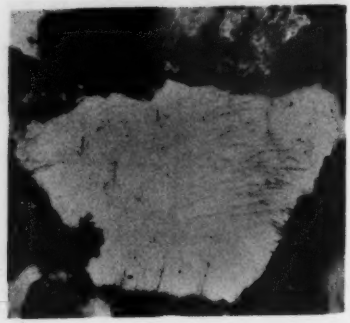

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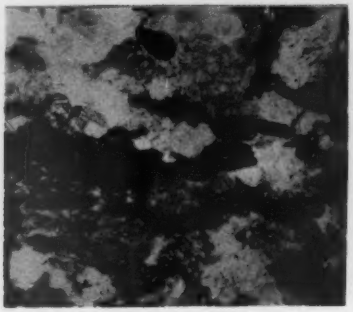

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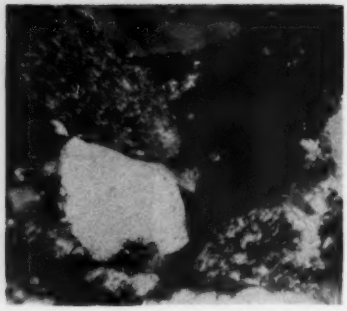

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MINERALOGY OF ROCKS

PLATE 2—MINERALOGY OF ROCKS

(1) A clear quartz grain and a quartz grain with irregular inclusions being replaced by calcite; crossed-nicols; x 100.

(2) Large quartz grain showing regrowth (probably pre-depositional); plane polarized light; x 100.

(3) Altered plagioclase grain, quartz, and contorted altered mica; crossed-nicols; x 70.

(4) Quartz grain showing pressure effects; crossed-nicols; x 100.

(5) Dark contorted altered mica in graywacke; plane polarized light; x 35.

(6) Calcite replacing quartz; crossed-nicols; x 100.